BASELINE MONITORING PLAN

Defense Coastal/Estuarine Research Program (DCERP)
Baseline Monitoring Plan

SERDP Project RC-1413

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Acronyms and Abbreviations

ADCIRC	Advanced Circulation
ADCP	Acoustic Doppler Current Profiler
ANCOVA	analysis of covariance
AOC	area of concern
AVP	autonomous vertical profiler
BBN	Bayesian Belief Network
BL	boundary layer
BP	barometric pressure
C	carbon
CAA	Clean Air Act
CAFO	confined animal feeding operation
CDOM	colored dissolved organic matter
CFR	Code of Federal Regulations
CH_4	methane
Cl^-	chloride
CO	carbon monoxide
COOPS	Center for Operational Oceanographic Products and Services
CORMP	Coastal Ocean Research Monitoring Program
CVA	change vector analysis
CWA	Clean Water Act
DCERP	Defense Coastal/Estuarine Research Program
DEM	Digital Elevation Model
DIC	dissolved inorganic carbon
DIN	dissolved inorganic nitrogen
DIP	dissolved inorganic phosphorus
DO	dissolved oxygen
DOC	dissolved organic carbon
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DON	dissolved organic nitrogen
EA	Environmental Assessment
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
ESM	Estuarine Simulation Model
Fe^{+2}	ferrous
FIB	fecal indicator bacteria
FWS	U.S. Fish and Wildlife Service
GIS	geographic information systems
GPS	global positioning system
GSRA	Greater Sandy Run Area
H	hydrogen
H_2S	hydrogen sulfide
HAB	harmful algal bloom
HPLC	high performance liquid chromatography
ICW	Intracoastal Waterway
INRMP	*Integrated Natural Resources Management Plan*

LCAC	Landing Craft Air Cushion
LIDAR	Light Detection and Ranging
MARSOC	Marine Special Operations Command
MCBCL	Marine Corps Base Camp Lejeune
MEM2	Marsh Elevation Model
MERIS	medium-spectral resolution, imaging spectrometer
μg/L	micrograms/liter
mg/L	milligrams/liter
MHW	mean high water
MODIS	moderate resolution imaging spectroradiometer
MOU	Memorandum of Understanding
MORPHOUS	modeling relevant physics of sedimentation
N	nitrogen
NAAQS	national ambient air quality standards
NCDAQ	North Carolina Division of Air Quality
NCDENR	North Carolina Department of Environment and Natural Resources
NCDWQ	North Carolina Division of Water Quality
NFDRS	National Fire Danger Rating System
NFESC	Naval Facilities Engineering Service Center
NH_3	ammonia
NH_4+	ammonium
NO_2	nitrogen dioxide
NO_3	nitrate
NOAA	National Oceanic and Atmospheric Administration
NO_x	nitrogen oxide
NPDES	National Pollutant Discharge Elimination System
NRE	New River Estuary
NWIS	National Weather Information System
NWS	National Weather Service
O_3	ozone
OPUS	Online Positioning System
OSC	On-site Coordinator
P	phosphorus, precipitation
PAR	photosynthetically active radiation
Pb	lead
PB	prescribed burning
PI	Principal Investigator
PM	Program Manager, particulate matter
PM_c	coarse particulate matter
$PM_{2.5}$, PM_{fine}	(fine) particulate matter with aerodynamic diameter smaller 2.5 microns
PM_{10}	particulate matter with aerodynamic diameter smaller 10 microns
$PM_{10\text{-}2.5}$, PM_c	(coarse) particulate matter aerodynamic diameter with between 2.5 and 10 microns)
PO_4^{-3}	phosphate
PP	primary productivity
PPT	precipitation
QA	quality assurance
QC	quality control
RCC	Regional Coordinating Committee
RCW	red-cockaded woodpecker
RDBS	Relational Database Management System

RH	relative humidity
RTI	RTI International
RTK	real-time kinetic
SAV	submerged aquatic vegetation
SE	standard error
SERDP	Strategic Environmental Research and Development Program
SET	surface elevation table
SI	Sustainable Infrastructure
SO_2	sulfur dioxide
SO_4^{-2}	sulfate
SOA	secondary organic aerosol
SOP	standard operating procedure
SRP	soluble relative phosphate
SWAN	Simulating Waves Nearshore Model
TAC	Technical Advisory Committee
TBD	to be determined
TM	Thematic mapper
TMDL	total maximum daily load
TSS	total suspended solid
UNC-IMS	University of North Carolina Institute of Marine Sciences
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
USMC	U.S. Marine Corps
VOC	volatile organic compounds
WCI	water clarity index
WD	wind direction
WQI	water quality index
WS	wind speed
WSM	Watershed Simulation Model
WWTP	wastewater treatment plant
YSI	Yellow Springs Instruments, Inc.

Baseline Monitoring Plan Executive Summary

Introduction

Critical military training and testing on lands along the nation's coastal and estuarine shorelines are increasingly placed at risk because of development pressures in surrounding areas, impairments due to other anthropogenic disturbances, and increasing requirements for compliance with environmental regulations. The U.S. Department of Defense (DoD) intends to enhance and sustain its training and testing assets and to optimize its stewardship of natural resources through the development and application of an ecosystem-based management approach on DoD facilities.

To accomplish the above goal, the Strategic Environmental Research and Development Program (SERDP) launched the Defense Coastal/Estuarine Research Program (DCERP) at Marine Corps Base Camp Lejeune (MCBCL) in North Carolina. MCBCL provides an ideal platform for DCERP because it integrates coastal barrier, estuarine, coastal wetland, and terrestrial ecosystems, all within the boundaries of DoD properties.

DCERP is designed to be implemented in two phases. Phase I of the program represents the planning period and includes the development of an overarching research strategy (*Defense Coastal/Estuarine Research Program Strategic Plan,* henceforth referred to as the DCERP Strategic Plan), design of an ecosystem-based monitoring program (*Defense Coastal/Estuarine Research Program Baseline Monitoring Plan,* henceforth referred to as the DCERP Baseline Monitoring Plan), identification of detailed research projects (*Defense Coastal/Estuarine Research Program Research Plan,* henceforth referred to as the DCERP Research Plan), and development of a data repository design. This phase was conducted between November 2006 and June 2007. Phase II of DCERP represents the program's implementation period and includes the execution of the DCERP Research Plan through field research; operation of the long-term ecosystem monitoring system; and collection, management, archiving, and analysis of data from both the research and monitoring components in the DCERP data repository. The Phase II implementation period will start in July 2007 and will last for a minimum of 4 years.

Program Organization

DCERP is a collaborative effort between SERDP, the Naval Facilities Engineering Service Center (NFESC), MCBCL, and the RTI International (RTI) DCERP Team. The overarching federal management for DCERP was assigned to NFESC. The DCERP PM is designated by NFESC and identifies the tasks and responsibilities of the RTI DCERP Principal Investigator (PI). The PI facilitates coordination with MCBCL through the DCERP On-site Coordinator (OSC). The DCERP OSC and MCBCL environmental managers will assist the DCERP PM and DCERP PI with the coordination of environmental monitoring and research activities on the Base.

Two committees will provide guidance and input to DCERP. The first, the Technical Advisory Committee (TAC), is a group of discipline experts assembled by the DCERP PM to provide scientific and technical review to ensure the quality and relevance of DCERP. The second committee, the Regional Coordinating Committee (RCC), is a group of local and regional stakeholders that serves as one of the recipients of outreach from MCBCL, the DCERP PI, and SERDP.

The RTI DCERP Team includes the PI, other environmental scientists from RTI, and researchers from the University of North Carolina Institute of Marine Sciences, North Carolina State University, University of North Carolina at Wilmington, Duke University, Virginia Institute of Marine Sciences, Virginia Tech, University of South Carolina, National Oceanic and Atmospheric Administration (Center for Coastal

Fisheries and Habitat Research, Beaufort, NC), U.S. Geological Survey (Raleigh, NC, office), URS Corporation, and Porter Scientific, Incorporated.

DCERP Overarching Strategy

The RTI DCERP Team has designed an integrative monitoring, modeling, and research strategy for MCBCL that is consistent with guidance on ecosystem-based management from the Ecological Society of America and recent recommendations from the U.S. Commission on Ocean Policy, including principles of adaptive management. This ecosystem-based management strategy will focus on the joint sustainability of military activities and fundamental ecosystem functions and services. The strategy will be designed around specific, quantifiable goals related to the status of resources (training and testing areas) that are central to the military mission of MCBCL.

MCBCL's Natural Resources Management

The mission of MCBCL is to provide military training that promotes the combat readiness of operating forces, and all natural resources management activities on the Base must support this mission. As a military installation, MCBCL has needs or drivers that must be satisfied for the installation's readiness mission to continue without significant disruption. Additionally, MCBCL must comply with related environmental laws and regulations, such as the federal Endangered Species Act (ESA) and Clean Water Act (CWA), to ensure continuance of the military mission.

Conceptual Model Development

To facilitate the understanding of the ecosystem state and dynamics of the MCBCL region necessary to complete Phase I, the RTI DCERP Team developed an overarching conceptual model for the MCBCL region. This model includes the terrestrial lands of MCBCL, the New River Estuary (NRE), associated coastal wetlands, and the coastal barrier along Onslow Bay, as well as the overarching influence of atmospheric conditions on the region (**Figure ES-1**).

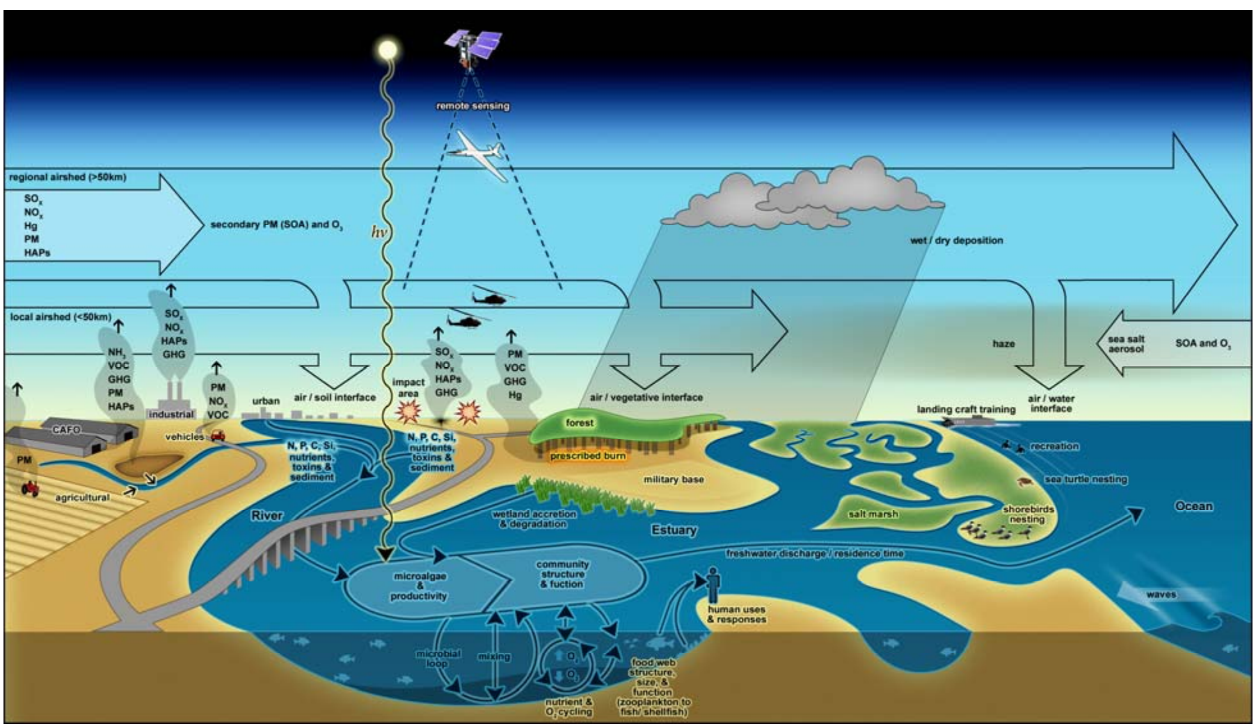


Figure ES-1. Overarching conceptual model for DCERP at MCBCL.

As an initial step in the planning effort, the overarching conceptual model was subdivided into four ecological modules: Aquatic/Estuarine Module, Coastal Wetlands Module (land-estuary margin), Coastal Barrier Module, and Terrestrial Module. These modules are linked to each other and to local and regional disturbances and pollutant sources of anthropogenic origin via atmospheric and aquatic transport mechanisms. Because the atmosphere has an overarching influence on all four ecosystem modules, it is treated as a fifth module (Atmospheric Module A sixth module (Data Management Module) involves a diverse group of specialists whose expertise will cut across all of the other modules to coordinate data management procedures for the DCERP data and information management system, which consists of three distinct systems: the Monitoring and Research Data Information System (MARDIS) for structured data, a Document Database for unstructured data, and the DCERP Web sites (consisting of a public Web site and a private collaborative Web site). The work conducted for the Data Management Module will include coordination of geospatial data, statistical analysis, and model integration. The RTI DCERP Team involves the participation of six module teams, one for each module, conducting monitoring and research activities under the direction of a Module Team Leader and Co-leader.

In addition to the overarching conceptual model depicted above, each of the ecosystem teams has developed a detailed conceptual model for their module. These individual conceptual models were developed to identify the key biological, chemical, and physical processes of the ecosystem, as well as the military, non-military, legacy, and natural ecosystem stressors that may affect the ecosystem.

Integrated Ecosystem-Based Management Approach

After developing the individual conceptual models early in Phase I of the program, the DCERP module teams identified knowledge gaps in the conceptual models and determined MCBCL management needs. The module teams then determined potential research questions to fill these knowledge gaps and to address MCBCL management needs. This DCERP Baseline Monitoring Plan is designed to gather environmental data to address MCBCL management concerns and to support the research projects identified in the Research Plan. During Phase II, results from research projects will feed back into this adaptive DCERP Baseline Monitoring Plan so that changes in the frequency and intensity of sampling, spatial scale of sampling locations, or parameters to be sampled can be made as necessary. Results from the monitoring and research efforts will be used to identify ecosystem indicators and to develop associated threshold values, tools, or design models that address MCBCL management needs. Once this information is transitioned to MCBCL, the Base’s natural resources managers will be able to make decisions about what type of management actions should be taken and then implement appropriate actions. After implementing these actions, the RTI DCERP Team will continue monitoring (feedback loop) to ensure that the desired management outcomes are achieved. This planning and implementation process is shown in **Figure ES-2**.

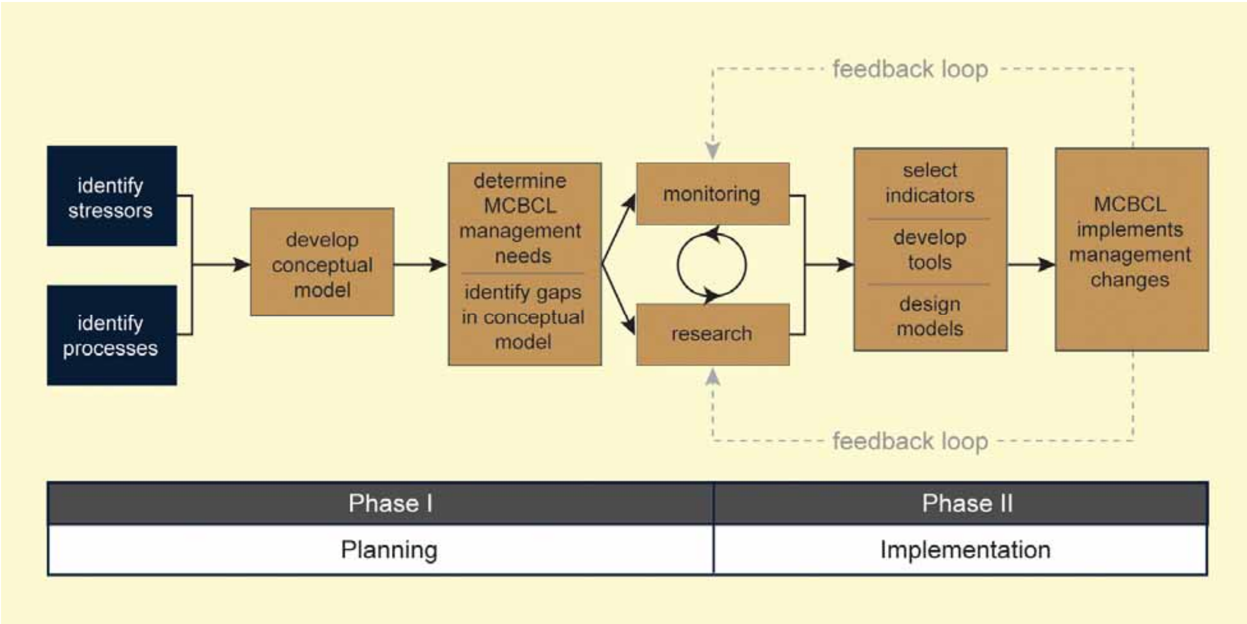


Figure ES-2. DCERP planning and implementation process flow chart.

Purpose of the Baseline Monitoring Plan

The purpose of this DCERP Baseline Monitoring Plan is to describe the baseline monitoring program that will be conducted at MCBCL to provide an historic reference of selected environmental parameters. The baseline monitoring data to be collected include the following:

- Basic fundamental parameters that support the broader ecosystem-based research agenda
- Parameters that provide data useful to more than one ecosystem module
- Parameters that must be monitored intensively and/or continuously for a minimum of 5–10 years to determine trends and natural variability.

The baseline monitoring program is seen as an adaptive program, in which monitoring may be adjusted over time in response to weather events, the availability of more efficient methods, and new information gained from ongoing monitoring and research efforts. At the end of the DCERP contract, it is the ultimate goal to transition to MCBCL a scaled-down version of the baseline monitoring program that identifies key measurement parameters for continued monitoring.

Summary of Monitoring Activities

The individual conceptual models for each ecosystem module have been used to identify knowledge gaps in the understanding of key ecosystem processes. DCERP Module Team Leaders have selected monitoring activities for inclusion in the baseline monitoring program that fill these knowledge gaps and address key Base management concerns. **Table ES-1** provides a summary of the module-specific monitoring activities proposed for the 4 implementation years.

Table ES-1. Summary of Module-Specific Monitoring Activities

Module	Activities
Coastal Barrier	Hydrodynamics: Wave velocity, wave heights/period, currents, shoreline position, morphology, and sediment volume. Meteorology (ocean): Air temperature, wind velocity, barometric pressure, humidity, solar radiation Sedimentology: Texture, compaction, composition Biology: Benthic invertebrates, shorebirds/seabirds, dune/shrub/marsh vegetation, sea turtles
Aquatic/ Estuarine[a]	Hydrodynamics: Stream flow and discharge (New River and tidal creeks) Chemistry: Nutrients, salinity, pH, oxygen, temperature (New River, NRE, tidal creeks) Sedimentology: Total suspended solids (New River, tidal creeks), turbidity (NRE) Biology: Primary productivity, phytoplankton, fluorescence (NRE)
Coastal Wetlands	Landcover and shoreline erosion: Location, elevation Hydrodynamics: Tide gauges (hydroperiod) Chemistry: Nutrients, salinity, hydraulic conductivity (shallow ground water) Sedimentology: Accretion rates, organic content, particle size
Terrestrial	Land cover/land use: Determine changes in land cover/land use (vegetation types, buildings, roads) and determine military training impacts Biology: Vegetative community assessment, fuel load Soil: Soil bulk density, pH, organic matter content
Atmospheric	Meteorology (air): Wind speed, wind direction, relative humidity, temperature, radiation, precipitation EPA Criteria Pollutants: Ozone, fine particulate matter (mass), sulfur dioxide

[a] Sedimentology, chemistry, and biology of the NRE benthic zone are characterized in the research program.

The DCERP baseline monitoring program also includes monitoring components that are general (not module-specific). The general monitoring includes several different types of environmental sampling that will provide data that are vital to all of the modules and will provide a holistic understanding of the Base's ecosystems. These general types of monitoring activities include the following:

- Land-based and sea-based meteorological data that will be acquired from the National Weather Service, UNC-Wilmington's Coastal Ocean Research and Monitoring Project, and on-site MCBCL meteorological stations, as well as meteorological data collected by the Atmospheric Module Team.
- Land-cover/land-use data that will be acquired from Landsat, IKONOS, Light Detection and Ranging (LIDAR), and MCBCL by the Terrestrial Module Team to conduct an analysis of land cover, land-use changes, and military activities.

Monitoring activities for the five ecological modules, including background information on the module, the knowledge gaps in the conceptual model that the monitoring data will fill, and the individual monitoring activities that are proposed for implementation, are discussed in this Baseline Monitoring Plan. Table ES-1 summarizes the DCERP monitoring activities, and **Figure ES-2** illustrates the location of the monitoring sites. This document provides specific design information for each of the monitoring activities, such as the objectives; methods; data analysis and outcomes; relevance to MCBCL; and linkages within the module and among the other modules for each of the 4 implementation years.

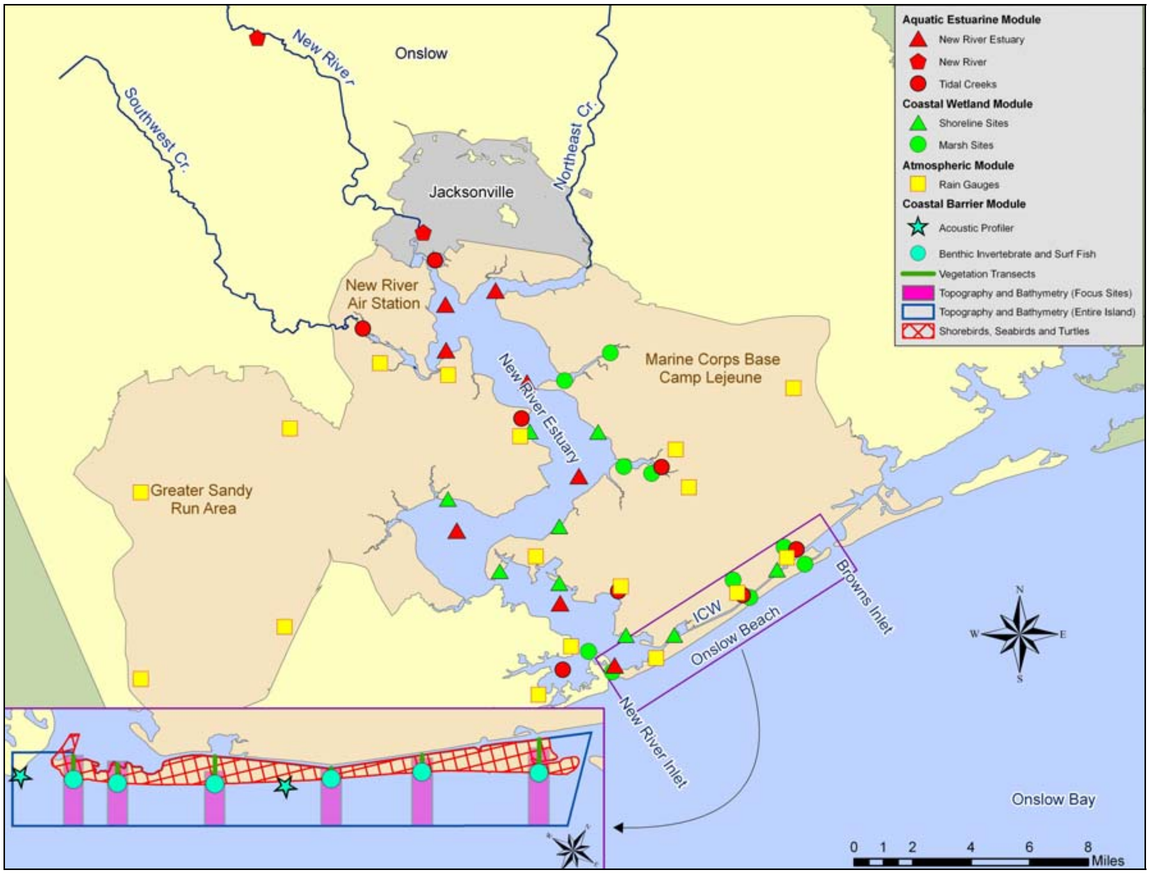
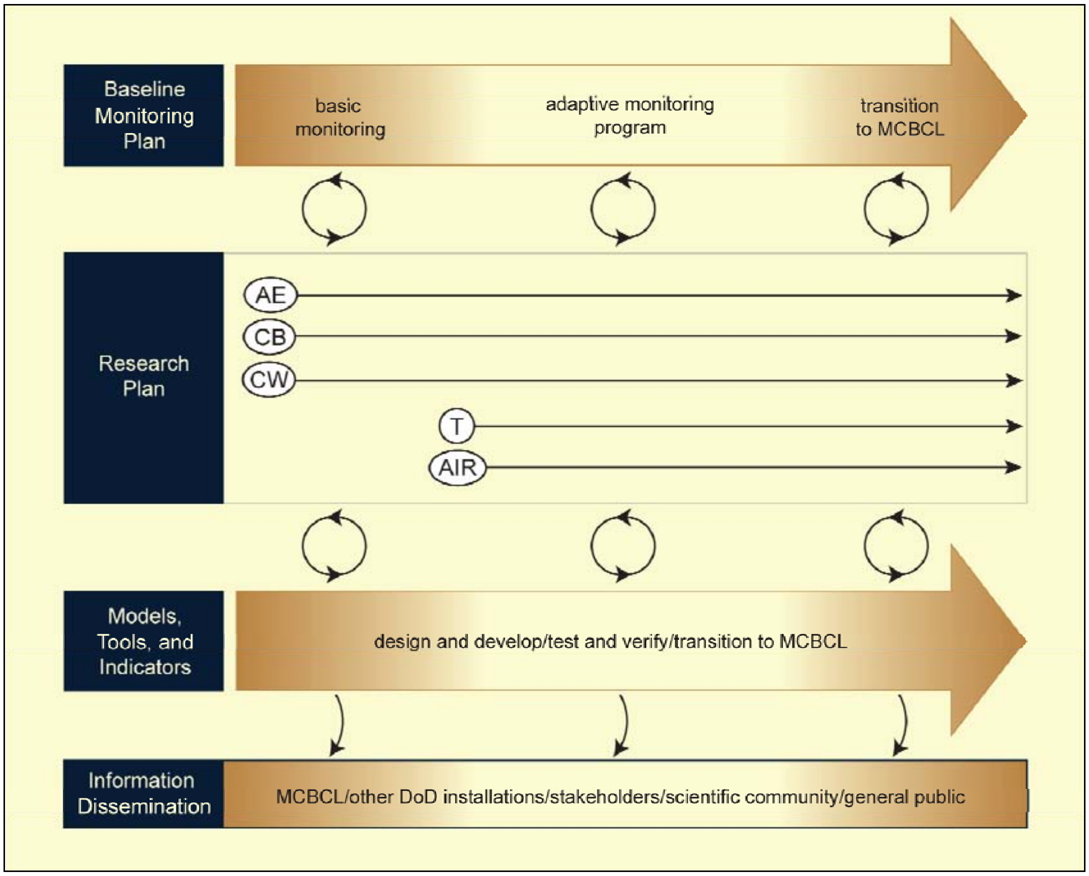


Figure ES-2. Proposed sample locations for DCERP's Baseline Monitoring activities.

Integration of Monitoring and Research

Appropriate data from the DCERP baseline monitoring program, as well as data from MCBCL environmental monitoring activities and other local, state, federal, and private monitoring activities, will be incorporated into the research program to provide an integrated approach to ecosystem-based management and to alleviate redundancy of data collection. Schedules and site locations for monitoring activities will be coordinated with the research program to ensure that linkages between the baseline monitoring sites and the research projects are maintained. Results from the research projects will feed back into this adaptive DCERP Baseline Monitoring Plan so that changes in the frequency of sampling, spatial scale of sampling locations, or parameters being sampled can be made as necessary (**Figure ES-3**). The models, tools, and indicators that are designed, developed, tested, and verified as part of the Baseline Monitoring and Research plans can be transitioned to MCBCL to assist in monitoring and forecasting ecosystem changes. In addition, it is a goal of DCERP to disseminate research results and information from associated models, tools, and indicators to MCBCL, as well as to other users groups, such as other DoD installations in similar ecological settings, the scientific community, other stakeholders (e.g. New River Roundtable or Onslow Bight Conservation Forum), and the general public.



Note: AE = Aquatic/Estuarine Module; CB = Coastal Barrier Module; CW = Coastal Wetlands Module; T = Terrestrial Module; AIR = Atmospheric Module

Figure ES-3. Generic roadmap of the integrated monitoring and research plans and the development of model tools and indicators.

Table ES-2 illustrates the overall linkages among the module-specific baseline monitoring activities and the individual research projects. For example, as can be seen from the bullets on the table, monitoring activities for the Aquatic/Estuarine Module will provide important monitoring data for the Aquatic/Estuarine Module research projects, as well as for the research efforts of the Coastal Wetlands and Coastal Barrier modules. Because the Atmospheric Module will conduct the general meteorological monitoring effort, and this data is important to all of the research efforts, it is identified as being linked to all of the research projects.

Table ES-2. Linkages among the Module-Specific Monitoring Activities and Research Projects

	AE- 1	AE-2	AE-3	CW-1	CW-2	CW-3	CB-1	CB-2	CB-3	T-1	T-2	Air-1	Air-2
Aquatic/Estuarine Monitoring	■	■	■		■	■	■	■					
Coastal Wetlands Monitoring	■	■	■	■	■	■				■			
Coastal Barrier Monitoring	■	■	■	■	■	■	■	■	■			■	■
Terrestrial Monitoring	■	■	■	■	■	■	■	■	■	■	■	■	■
Atmospheric Monitoring	■	■	■	■	■	■	■	■	■	■	■	■	■

Data Management Module

The backbone of the DCERP research, modeling, and management tools will be environmental data collected throughout the duration of the program. The types and volumes of baseline data that currently exist (historical data) and that will be collected during the DCERP monitoring and research programs are extensive. It is essential that a comprehensive data management plan be developed and implemented to ensure that these data are accessible to researchers across modules. General categories of data to be collected and managed include the following: structured data (e.g., monitoring and research data), unstructured data (e.g., Web sites, reports, and publications), and spatial data (e.g., vector and raster).

The Data Management Module will develop a data and information management system to support the other DCERP modules. The DCERP data and information management system will consist of three distinct systems: the Monitoring and Research Data Information System (MARDIS), a Document Database, and the DCERP Web sites (consisting of a public Web site and a private collaborative Web site). MARDIS will store and manage the data collected by the DCERP module teams, and the Document Database will store unstructured data, such as documents, for easy retrieval by the DCERP Team.

Transitioning Monitoring Program to MCBCL

The DCERP baseline monitoring program was designed with the goal of transitioning a scaled-down version of the program to MCBCL at the end of the project (or sooner, if the Base management so desires). MARDIS will standardize the storage of monitoring data, and the results will be summarized in quarterly and annual reports and submitted to SERDP and MCBCL. Six months prior to the completion of DCERP, the RTI DCERP Team will work with Base personnel to begin transitioning this DCERP Baseline Monitoring Plan to MCBCL. This transition will involve hands-on training for MCBCL staff in the use of the equipment, including the transfer of all SOPs and an overview of data analysis procedures and reporting. Ultimately, all monitoring activities and data collected as part of DCERP will be transitioned to the Base.

Measures of Success/Outcomes

The successful implementation of DCERP will foster a greater understanding of the biologically diverse aquatic/estuarine, coastal wetland, coastal barrier, and terrestrial ecosystems of MCBCL; the Base's air quality; and the interactions of these systems with military training activities. This understanding will aid in the long-term management and sustainability of MCBCL's ecosystems, thereby enhancing and maintaining MCBCL's military mission. Information and data resulting from DCERP monitoring efforts

will increase the ability of natural resources managers to perform assessments and implement appropriate management responses to potential environmental impacts arising from military activities or natural disturbance events. In addition, the DCERP monitoring metrics and techniques will likely be transferable to other DoD sites in ecologically similar settings.

Measurements of DCERP's success will come from assessing whether the program's outcomes were achieved in a timely manner. The outcomes defined for DCERP can be grouped into two main categories:

- Programmatic—Includes administrative requirements, such as delivering required documents on schedule and on budget, ensuring that the project Web site is developed and functioning, meeting SERDP quarterly and annual reporting requirements, and providing timely and effective feedback to MCBCL and outreach to stakeholders.
- Project specific—In some cases, these outcomes provide information to address environmental issues that are currently impacting Base operations. Other monitoring efforts were designed to provide outcomes relevant to issues that are currently known and that are anticipated to impact Base operations in the next 3–5 years. In addition, the majority of DCERP research and monitoring activities will provide information necessary to gain a complete understanding of ecosystem functions, which will better prepare the Base managers to address future environmental issues.

Project-specific outcomes associated with individual monitoring efforts are provided in **Table ES-3**. Specific programmatic and overarching strategic outcomes are included in the DCERP Strategic Plan.

Table ES-3. Important Outcomes of Module-Specific Monitoring Activities

Monitoring Activity	Aquatic/Estuarine Module Outcomes	Completion Date
New River Monitoring	River discharge and tide data will be used for placing nutrient and sediment samples in the appropriate hydrologic and tidal context.	June 2010; ongoing
	To distinguish upstream inputs from Base sources, river discharge, nutrient, and sediment data will be used in the hydrodynamic models developed in Research Projects CB-1 and CB-2 and the Watershed Simulation Models (WSMs) and Estuarine Simulation Model (ESM) developed in Research Projects AE-1, AE-2, and AE-3 to compute the daily loadings of nutrients and sediment being transported into the estuary from upstream sources.	June 2010; ongoing
Tidal Creek Monitoring	Water velocity, nutrient, and suspended particle data will be used to estimate loadings of nutrients and sediments. Nutrient and sediment loading rates from creeks will be used in hydrodynamic models developed in Research Projects CB-1 and CB-2 and the WSMs and ESM developed in Research Projects AE-1, AE-2, and AE-3.	June 2011
	Suspended sediment loads will be used in the Marsh Elevation Model (MEM2) developed in Research Project CW-1 because these loading represent an importation source for marsh accretion. Thresholds for minimum sediment loading required to support MCBCL marsh accretion will be assessed.	June 2011
New River Estuary - Water Column Chemistry	Water velocity and nutrient and particle suspensions will be used to estimate flux and loading of nutrients and sediments to the NRE. Nutrient and sediment loading rates will be applicable to the WSMs and ESM developed in Research Projects AE-1, AE-2, and AE-3.	June 2011
	Suspended sediment loads will be used in the MEM2 developed in Research Project CW-1 because these loadings represent an important source for marsh accretion.	June 2011
New River Estuary - Water Column	Maps of primary production, phytoplankton biomass, and harmful algal blooms (HABs) will be developed.	June 2008; ongoing

Monitoring Activity	Aquatic/Estuarine Module Outcomes	Completion Date
New River Estuary - Primary Producers	The space-time relationships between nutrient, sediment, and other contaminant inputs, and phytoplankton production responses under variable hydrologic conditions will be examined.	June 2008; ongoing
	Chlorophyll *a* and associated results will be used in the ESM being constructed in Research Project AE-3 and the Bayesian Probabilistic Model being developed in Research Project AE-1.	June 2011
	Phytoplankton results will be formatted to serve as calibration and verification data for remote-sensing efforts aimed at scaling up production and HAB dynamics to the entire estuary.	June 2010; ongoing
	Indicators for chlorophyll *a* and associated physical-chemical parameters will be used to identify NRE sites with healthy, transitional, and poor condition. These indicators will identify areas of the NRE that meet North Carolina and EPA acceptable water quality standards for estuaries.	June 2008; ongoing
Monitoring Activity	**Coastal Wetlands Module Outcomes**	**Completion Date**
Land Cover and Shoreline Erosion	Distribution of coastal wetlands along salinity, wave exposure, and elevation gradients will be determined, and this data will be used in ecosystem models to predict how changes in environmental variables, sea-level rise, or disturbance may alter distribution of NRE coastal wetlands.	June2011
	Maps and GIS layers of marsh distribution and species composition, elevations, shoreline delineation, and wave energy will be developed to identify shoreline areas vulnerable to erosion.	June 2008; ongoing
Marsh Surface Elevation	Spatial and temporal variation in marsh elevation change and accretion rates will be incorporated into a MEM2, developed in Research Project CW-1, which will forecast coastal wetland response to sea-level rise and nutrient additions, and a Shoreline Erosion Model (NRESE developed in Research Project CW-2) that forecasts NRE shoreline erosion	June 2011
	Water level data will be used in combination with marsh elevation distribution to calculate flooding times (hydroperiod) for coastal wetlands.	September 2009; ongoing
Marsh Groundwater and Nutrients	Water/nutrient fluxes will be estimated first by using a groundwater flow model calibrated with hydraulic head, hydraulic conductivity, and salinity. Then, a Coupled Water and Salt Mass Balance Model will be constructed to independently quantify all components of the marsh water budget (developed in Research Project CW-3).	January 2010
	The coastal wetland piezometer networks will determine water flowpath direction, velocity, flux rates, and water-residence times.	December 2008
	The water budget of the marsh subsurface depends on tidal and shallow groundwater-forcing functions. The magnitude of these forcing functions changes seasonally with the rise and fall of the water table and tidal amplitude. Nutrient inventory changes primarily seasonally in response to temperature. The flowpath direction, velocity, fluxes, and residence times for water and nutrients can be correlated to water table height, tidal range, and temperature. Collectively these parameters should serve as a metrics or tool for the future assessment of seasonal marsh connectivity to, and moderation of nutrient loads from, the adjacent watershed and estuary.	January 2010

Monitoring Activity	Coastal Barrier Module Outcomes	Completion Date
Hydrodynamics (Oceanographic data)	Data will be analyzed using traditional time-series analysis, as well as wavelet analysis techniques (Fourier Transform Analysis), to decipher key tidal frequencies, their amplitudes, and their contributions to the variability of flow within this system. This information will be used in the ADvanced CIRculation (ADCIRC) model developed by the Coastal Barrier Module's research projects.	June 2010
Hydrodynamics and Nearshore Bathymetry	Geo-rectified maps of the shoreline and nearshore sandbars will be developed using mobile radar data. These data will facilitate an understanding of sediment transport pathways and recovery from storms or military operations on Onslow Beach.	June 2009; ongoing
Shoreface Bathymetry	Shoreface bathymetry maps will be developed in geo-rectified formats using high-density, 3-D point data. These maps will illustrate sediment volume changes through time, providing an understanding of sediment-transport processes. The bathymetry data will be used in the Short-term Barrier Evolution and Long-term Barrier Evolution models being developed in Research Projects CW-1 and CW-2, respectively.	June 2009; ongoing
Barrier Morphology	Barrier topography maps will be developed in geo-rectified formats using high-density, 3-D point data. Maps showing sediment-volume changes through time will be produced, indicating areas vulnerable to storm surge and sea-level rise.	June 2009; ongoing
	Maps showing changes in the position of the foreshore/backshore and backshore/dune transitions and the aerial extent of these environments will be produced.	June 2009; ongoing
Sediment Texture	A summary report will be developed that provides graphs of sediment texture (individual weight percent versus diameter) for each sediment sample. Maps showing changes in sediment texture through time will be developed. Changes in sediment texture will be used as an indicator of habitat quality and extent. For example, foraging success, turtle-nesting site locations, and sediment transport are all controlled, in part, by sediment texture.	June 2009; ongoing
Benthic Invertebrates	The mean density and abundance of benthic invertebrates along the barrier will be quantified and evaluated with respect to wave energy and sediment transport, sediment composition, and shorebird feeding and nesting success. A report will be developed that summarizes these results.	June 2011
	A reliable index of habitat value for foraging shorebirds and surf fishes that is based upon the biomass of key prey taxa of benthic macroinvertebrates will be developed.	June 2011
Surf Fish and Sea Turtles	Data on abundances of surf fishes will be compiled as means of each species per site. Effects of disturbance levels along the beach on surf fish abundance (total and by species) will be determined and summarized in a report.	June 2011
	An evaluation of the factors determining whether site selection for sea turtle egg laying and hatching success varies significantly with the presence of erosion scarps, foredunes of various elevations, sediment grain size, shell content of sediments, and sediment hardness will be conducted, with the results presented in a summary report.	June 2011
	An interdisciplinary evaluation of the site-specific need for beach nourishment based on shoreline erosion rates will be presented in a report. Guidance on the range of sediment types that preserve habitat value for nesting sea turtles and feeding and nesting of key shorebirds and guidance on whether to restore the dune line during beach nourishment will also be presented in a report.	June 2011

Monitoring Activity	Coastal Barrier Module Outcomes	Completion Date
Shorebirds and Seabirds	Data on bird abundance and reproductive indices will be analyzed and linked to the various ecosystem components of the coastal barrier. A summary report that presents these analyses will be prepared.	June 2011

Monitoring Activity	Terrestrial Module Outcomes	Completion Date
Plant species composition, diversity, and distribution	Tree density and volume, herbaceous cover and diversity, and fuels will be determined for each plot using the standard summary statistical metrics. Compositional variation among individual plots will be assessed using PC-ORD software.	June 2010
	Spatial and temporal vegetation change data (e.g., composition, diversity, fuel loads) will be evaluated using Mantel and partial Mantel models (Research Project T-1). A detailed model relating species diversity and surface fuels to site conditions and disturbance history will be developed.	June 2010
	Fuel load measures will be used in the U.S. Forest Service National Fire Danger Rating System (NFDRS) model (Research Project T-1) to assess plot and area fire risk.	June 2010
Assessment of Land use/Land cover Change	GIS datalayers of historic (early 1980s) and existing landcover, topographic LIDAR, Landsat, and hydrography NHD+ data will be compiled.	June 2008
	Integration of military use data with land-cover change analysis will be conducted to provide use statistics for micro watersheds.	June 2008
	A spatially explicit map and dataset of land-use change for the New River watershed will be developed using historic and current Landsat data and updated as needed.	June 2009; ongoing
	A land cover change report will be develop encompassing the initial 4-year period of DCERP.	June 2011
Monitoring Activity	**Atmospheric Module**	**Completion Date**
Air Quality	A reliable, temporally, and spatially highly resolved set of air quality and meteorological data for both the local MCBCL area and surrounding area (within 100 km radius) will be developed.	June 2009

1.0 Introduction

The U.S. Department of Defense (DoD) intends to enhance and sustain its training and testing assets and to optimize its stewardship of natural resources through the development and application of an ecosystem-based management approach on DoD facilities. DoD policy has established ecosystem-based management as the preferred approach for military lands (Goodman, 1996). This management approach will focus on sustaining and enhancing military operations by monitoring and managing the interdependent natural resource assets on which the future of those operations depend. To expand its commitment to improving military readiness while demonstrating the science behind this approach, the Strategic Environmental Research and Development Program (SERDP) has made a long-term commitment of at least 10 years to fund research and monitoring projects that support the sustainability of military training and testing in ecologically and economically important ecosystems.

To accomplish the above goal, SERDP has launched the Defense Coastal/Estuarine Research Program (DCERP) at Marine Corps Base Camp Lejeune (MCBCL) in North Carolina. (Note: DCERP is the second such program to use an ecosystem-based management approach — the first is the SERDP Ecosystem Management Project, which has been ongoing at Fort Benning, GA, since December 1997.) MCBCL provides an ideal platform for DCERP because it integrates coastal barrier, estuarine, coastal wetland, and terrestrial ecosystems, all within the boundaries of DoD properties.

MCBCL was chosen as the DCERP site for a variety of reasons, including the following:

- The New River Estuary (NRE) watershed, which borders the site, is relatively small and, therefore, manageable
- MCBCL occupies a substantial portion (~80%) of the NRE shoreline
- A barrier island/coastal dune system occurs within MCBCL’s boundary and provides a unique amphibious assault training environment
- The variety of ongoing military operations at MCBCL enables researchers to examine training impacts on a broad range of ecosystems, from upland pine savannas to aquatic/estuarine waters to coastal barriers.

Figure 1-1 provides a map of MCBCL in Onslow County, NC, and the surrounding watershed area.

Figure 1-1. Site map of MCBCL.

As stated in the initial DCERP Strategy, *"The overall intent of the DCERP is to develop the knowledge required to assess the interaction between military activities and ecological resources in a coastal/estuarine setting, monitor those interactions, and identify adaptive, ecosystem management approaches for sustainment of military lands and adjacent waters"* (SERDP, 2005). DCERP is designed to conduct relevant research and monitoring, develop and apply indicators, and provide MCBCL resource managers with assessment tools and criteria in support of ecosystem management.

RTI International (RTI), headquartered in Research Triangle Park, NC, is leading the DCERP research and monitoring effort. RTI has assembled a diverse team of experts in relevant disciplines of environmental science with many years of experience working together on interdisciplinary coastal, estuarine, and terrestrial ecosystem projects. The RTI DCERP Team will address the initial DCERP Strategy by developing monitoring approaches and identifying key ecological processes through research and modeling studies, all with the goal of supporting the practice of ecosystem management at other coastal DoD installations in similar ecological settings.

DCERP is designed to be implemented in two phases. Phase I of the program represents the planning period and includes the development of an overarching research strategy (*Defense Coastal/Estuarine Research Program Strategic Plan*, henceforth referred to as the DCERP Strategic Plan), design of an ecosystem-based monitoring program (*Defense Coastal/Estuarine Research Program Baseline Monitoring Plan*, henceforth referred to as the DCERP Baseline Monitoring Plan), identification of detailed research projects (*Defense Coastal/Estuarine Research Program Research Plan*, henceforth referred to as the DCERP Research Plan), and development of a data repository design.

Phase II of DCERP represents the program's implementation period and includes the execution of the DCERP Research Plan through field research; operation of the long-term ecosystem monitoring system; and collection, management, archiving, and analysis of data from both the research and monitoring components into the DCERP Monitoring and Research Data Information System (MARDIS).

The Phase I planning period for DCERP was conducted between November 2006 and June 2007. The Phase II implementation period will start in July 2007 and will last for a minimum of 4 years.

2.0 Program Organization

DCERP is a collaborative effort between SERDP, the Naval Facilities Engineering Service Center (NFESC), MCBCL, and the RTI DCERP Team selected to execute the objectives of SERDP's Ecosystem Management Project. **Figure 2-1** illustrates the overall organization and lines of communication of DCERP.

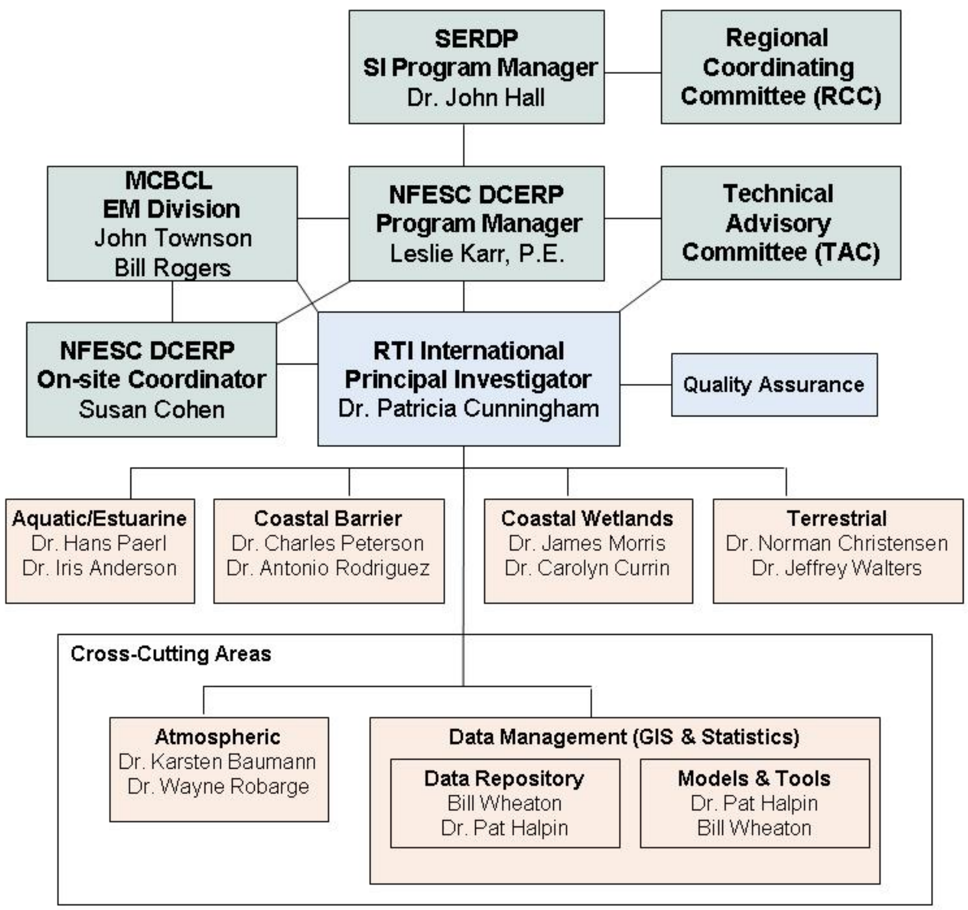


Figure 2-1. Organization of DCERP.

SERDP is an environmental research and development program, planned and executed by the DoD in full partnership with the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA). The SERDP Sustainable Infrastructure (SI) Program Manager (PM), Dr. John Hall, ensures that DCERP activities provide for the enhanced knowledge of ecosystem and military interactions within approved scopes of work and budgets. The overarching federal management for DCERP was assigned to NFESC. The DCERP PM, Ms. Leslie Karr, is designated by NFESC and identifies the tasks and

responsibilities of the RTI DCERP Principal Investigator (PI), Dr. Patricia Cunningham. As PI, Dr. Cunningham facilitates coordination of the RTI DCERP Team with MCBCL through the DCERP On-site Coordinator (OSC), Ms. Susan Cohen. At MCBCL, the DCERP OSC, the Director of the Environmental Management Division, Mr. John Townson, and the Head of the Environmental Conservation Branch, Mr. Bill Rogers, assist the DCERP PM and DCERP PI with the coordination of environmental monitoring and research activities on the Base. The DCERP OSC is the primary point of contact between MCBCL and the RTI DCERP Team.

Two committees will provide guidance and input to the RTI DCERP Team. The first, the Technical Advisory Committee (TAC), is a group of discipline experts assembled by the DCERP PM to provide scientific and technical review to ensure the quality and relevance of DCERP. The TAC directs all questions and comments to the DCERP PM. The second committee, the Regional Coordinating Committee (RCC), is a group of local and regional stakeholders that serves as one of the recipients of outreach from MCBCL, the DCERP PI, and the SERDP PM.

The DCERP PI is responsible for the overall scientific quality, cohesiveness, and relevance of the DCERP Baseline Monitoring Plan and DCERP Research Plan. In addition, the DCERP PI is the primary point of contact for SERDP and MCBCL and coordinates all DCERP activities conducted at MCBCL through the DCERP OSC, Ms. Cohen. The RTI DCERP Team has been organized into six module teams based on the ecosystem-based management objectives for the program. Each module team falls under the direction of a Module Team Leader and Co-leader. These module teams conduct monitoring and research activities for DCERP's five ecosystem modules (Aquatic/Estuarine Module, Coastal Barrier Module, Coastal Wetlands Module, Terrestrial Module, and Atmospheric Module) and the Data Management Module. This DCERP Baseline Monitoring Plan builds on the approach established in the DCERP Strategic Plan and provides details on the monitoring program proposed for each ecosystem module, as well as how the monitoring program will be integrated with the research projects. The six ecosystem modules will be discussed in further detail in Section 6 of this plan (*Module-Specific Baseline Monitoring*).

3.0 DCERP Overarching Strategy

The RTI DCERP Team has designed an integrative monitoring, modeling, and research strategy for MCBCL that is consistent with guidance on ecosystem-based management from the Ecological Society of America (Christensen et al., 1996) and recent recommendations of the United States Commission on Ocean Policy (2004), including principles of adaptive management (Walters, 2001). This strategy transcends air-land-water boundaries to better understand the causes and nature of ecological and environmental change across the region, as well as locally at MCBCL. Based on interconnectivity, this strategy helps separate the underlying natural (e.g., climatic or biogenic) and anthropogenic regional processes from locally driven changes; identifies stressor-specific indicators of ecosystem status that provide early warning of ecosystem degradation; and specifies critical thresholds for indicators of potential state shifts that could threaten sustainability. A threshold is a point at which further degradation in ecosystem condition will result in the system's inability to return to its initial state without significant intervention (SERDP, 2005). The biological, chemical, geological, and physical ecosystem processes are summarized in scientifically rigorous conceptual models; these models incorporate an understanding of the dynamic processes that interconnect ecosystem components in often complex ways. **Figure 3-1** presents the overarching conceptual model for the MCBCL region, which includes the terrestrial lands of MCBCL, the NRE, associated coastal wetlands, and the coastal barriers along Onslow Bay, as well as the overarching influence of atmospheric conditions.

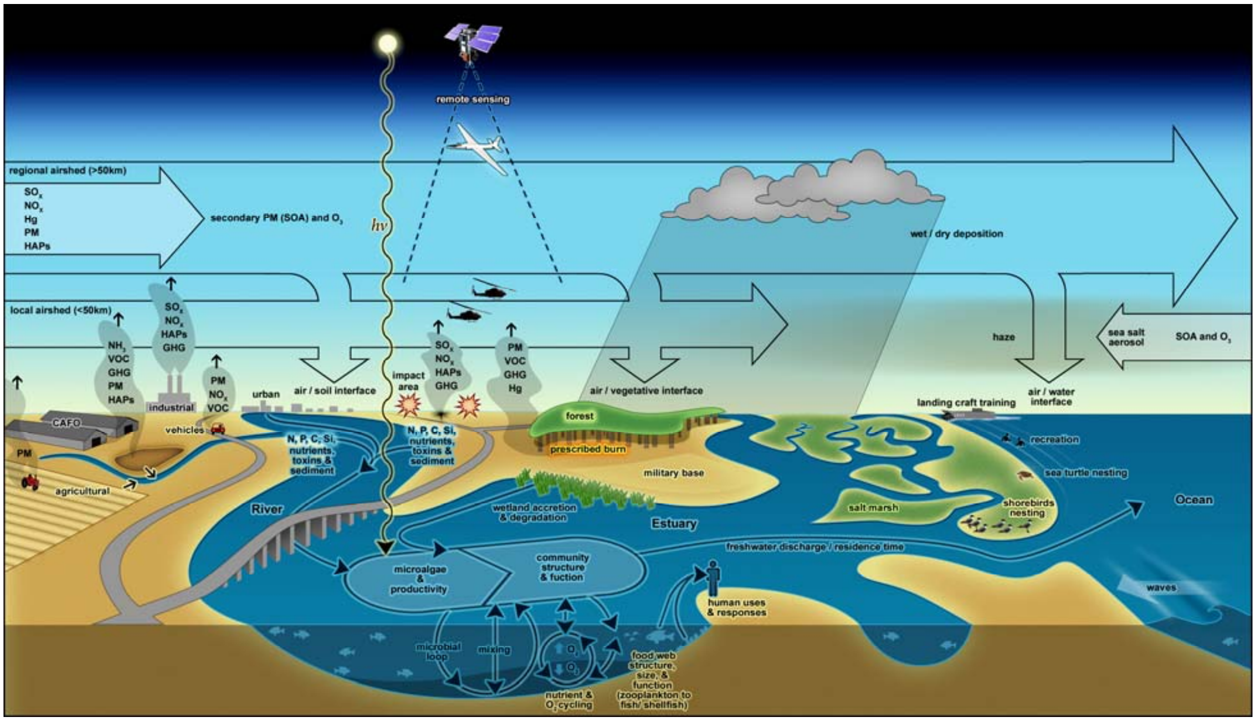


Figure 3-1. Overarching conceptual model for DCERP at MCBCL.

To facilitate an understanding of the ecosystem state and dynamics of the MCBCL region, the RTI DCERP Team subdivided the ecosystem into four ecological modules for monitoring, modeling, and research: the Aquatic/Estuarine Module, Coastal Wetlands Module (land-estuary margin), Coastal Barrier Module, and Terrestrial Module. These modules are linked to each other and to local and regional disturbances and pollutant sources of anthropogenic origin via atmospheric and aquatic transport mechanisms. Because the atmosphere has an overarching influence on all four ecosystem modules, it is treated as a fifth module (Atmospheric Module). Individual conceptual models for each of the modules are presented in Section 6 (*Module-Specific Baseline Monitoring*).

The ecosystem-based management strategy will focus on the joint sustainability of military activities and fundamental ecosystem functions and services. The strategy will be designed around specific quantifiable goals related to the status of resources (training and testing areas) that are central to the military mission of MCBCL. Assessments of how to manage military activities in ways that sustain the value of natural ecosystem assets will be regularly delivered to MCBCL natural resources managers. In addition, these assessments will be integrated into the ecological conceptual models, biogeochemical syntheses, and environmental and geographic information systems (GIS) databases that will be perpetuated as a legacy of MCBCL's commitment to environmental sustainability.

A sixth module, the Data Management Module, involves a diverse group of specialists whose expertise will cut across all of the other modules to coordinate data management procedures for the DCERP data repository, including coordination of geospatial data, statistical analysis, and model integration. The Data Management Module involves both a data and information management systems component, which includes the data repository (MARDIS), and a models and tools component. SERDP conceived MARDIS as being developed to facilitate the collection and storage of environmental data collected by the RTI DCERP Team, as well as to be the permanent repository for research and monitoring data collected during the DCERP implementation. The models and tools component provides the ultimate cross-cutting

function of integrating the simple models, developed in the individual research projects, into integrated management models.

During the first few years of the program, the RTI DCERP Team will develop models and management tools that reflect advances in GIS and spatial and time-series modeling and biological, chemical, and physical processes. This development will be supported by resources allocated to the individual modules. In later years, however, development of calibrated, tested, and operational management models will be proposed for funding as part of the Data Management Module. Management models need to be usable by natural resource and watershed managers and fully tested so they are of known reliability; therefore, these models will be archived in the data repository for development and final calibration and testing before they are made available to MCBCL.

3.1 MCBCL's Natural Resources Management

The mission of MCBCL is to provide military training that promotes the combat readiness of operating forces, and all natural resources management activities on the Base must support this mission. An introduction to the military operations of MCBCL is provided in **Appendix A**. As a military installation, MCBCL has needs or drivers that must be satisfied for the installation's readiness mission to continue without significant disruption. Additionally, MCBCL must comply with related environmental laws and regulations, such as the federal Endangered Species Act (ESA) and the Clean Water Act (CWA), to ensure continuance of the military mission. To ensure such compliance, MCBCL has adopted an *Integrated Natural Resources Management Plan* (INRMP) (MCBCL, 2006a), which outlines the Base's conservation efforts and establishes procedures for fiscal years 2007 through 2011. One goal of the INRMP is to minimize future training restrictions (no net loss in the ability to train) by increasing integration between natural resources management planning, training, and operations. It is the goal of DCERP to assist MCBCL in achieving this goal.

Unique to MCBCL are installation-specific drivers that are defined by the Base's mission and geographic location, land uses to support the mission, and natural resources affected by the mission. Identification of the primary military drivers at the Base provided the basis for establishing six natural resource management objectives for MCBCL's INRMP (MCBCL, 2006a). These six natural resources management objectives are the following:

1. Preserve the integrity of the amphibious maneuver areas, including Onslow Bay, the NRE, and the adjoining training areas and airspace of MCBCL.
2. Preserve the integrity of MCBCL as a combined-arms training base by ensuring the continued viability of its impact areas and associated training ranges.
3. Enhance future training uses of MCBCL ranges, training areas, and airspace by fully integrating the *Land Use Master Plan* (MCBCL, 2005) and *Range Transformation Plan* (MCBCL, 2006b).
4. Ensure that MCBCL supports all required military training activities while complying with the ESA and other wildlife requirements.
5. Ensure that MCBCL supports continued military training use of the New River, the NRE, and Onslow Bay by complying with the CWA.
6. Ensure the viability of the New River Air Station as an aviation facility through the elimination of bird and wildlife strike hazards to aircraft while complying with the ESA and other wildlife regulatory requirements.

In addition to these military drivers, MCBCL natural resources staff have identified a prioritized list of conservation and water quality needs that will support implementation of the INRMP. **Appendix B** illustrates the Base's needs and identifies the DCERP approach for addressing these needs. As part of

DCERP, every effort will be made to address areas of concern (AOCs) that are not currently being investigated or to improve upon existing programs that are attempting to address these AOCs.

3.2 Conceptual Model Development

Each of the five ecosystem modules has developed a conceptual model. As described in the DCERP Strategic Plan, these models were developed to include the key biological, chemical, and physical processes of the ecosystem, as well as the military, non-military, legacy, and natural ecosystem stressors that may affect the model (**Figure 3-2**).

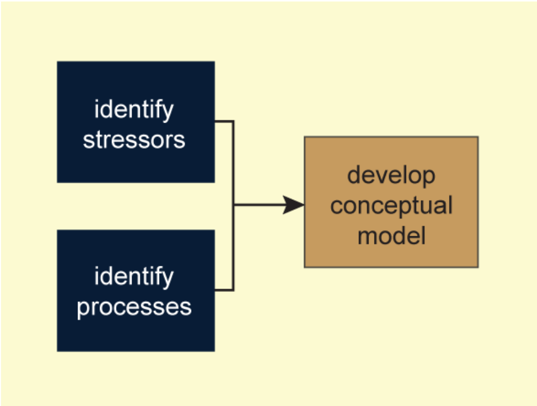


Figure 3-2. Development of the conceptual model.

The focus of the DCERP monitoring and research effort includes biological processes (e.g., primary production and respiration), chemical processes (e.g., water column and sediment nutrient processing/cycling and atmospheric transformations), and physical processes (e.g., hydrodynamics of the NRE and sediment transport along Onslow Beach), which are described in the individual module narratives**.** These key biological, chemical, and physical processes are the driving forces of the function of the ecosystem in the absence of stressors. Although the main processes are generally understood, the biological, chemical, and physical ecosystem processes at MCBCL have not been researched extensively, especially within the context of outside stressors. For DCERP, stressors are defined as activities or events that alter natural ecological processes. The RTI DCERP Team has grouped stressors into four major categories: military, non-military, legacy, and natural. **Table 3-1** provides a definition for each category, as well as specific examples relevant to DCERP. The conceptual models developed for each module were designed to integrate the ecological processes and stressors with the Base's military drivers and conservation and water quality needs, as determined by MCBCL for the management of natural resources. The key military drivers and natural resources management needs are listed in Section 3.1 of this report (*MCBCL Natural Resources Management*). For more information on these drivers, please refer to MCBCL's INRMP (MCBCL, 2006a).

Table 3-1. Examples of Military, Non-Military, Legacy, and Natural Ecosystem Stressors

Stressor	Examples
Military	Military stressors are unique activities or events associated with military training and testing at MCBCL, including the use of military tracked vehicles, amphibious watercraft, and boats; troop movements on the Base; and the use of firing ranges and impact areas. For example, the direct effects of military activities on the NRE include the resuspension of bottom sediments in shallow water areas or physical damage to benthic communities when training boats are launched. In addition, indirect effects of military activities may include erosional runoff from training areas where vehicles and troops have compacted or otherwise disturbed the soil surfaces and bank erosion due to the movement of amphibious watercraft near splash points.
Non-military	Non-military stressors include any anthropogenic activities that can occur on Base or off Base, including runoff of nutrients from confined animal feeding operations (CAFOs), agricultural practices, or urban lands; discharges from industrial facilities and municipal wastewater treatment plants (WWTPs); runoff of land-applied sewage sludge; atmospheric deposition of nutrients and contaminants; groundwater withdrawals; local residential or commercial development; emissions from non-military vehicles; prescribed burning (PB) activities; and commercial and recreational fishing pressures.
Legacy	Legacy stressors are anthropogenic activities that have occurred in the past whose effects are continuing today. Examples include the construction of the Intracoastal Waterway (ICW), early ditching activities to drain land, the historic use of fire, agricultural activities, timber harvesting, and dischargers of nutrients by the City of Jacksonville WWTP (this discharge was eliminated in 2000).
Natural	Natural stressors include natural forces (e.g., hurricanes and sea level rise) whose effects are enhanced by anthropogenic activity (global warming). The increased frequency and intensity of natural events, in combination with anthropogenic contributions, could cause ecosystem perturbations outside the range of natural variation.

3.3 Integrated Ecosystem-Based Management Approach

Figure 3-3 illustrates the overall process that will be used to meet the DCERP objectives. After developing individual conceptual models in Phase I, the DCERP module teams identified knowledge gaps in the models and determined the needs of MCBCL management. The module teams then determined potential research questions to fill these basic knowledge gaps and to address MCBCL management needs. DCERP is a research-initiated process that is distinct from other ecosystem-based programs that are driven by specific regulatory or management objectives. This DCERP Baseline Monitoring Plan is designed to gather environmental data to address MCBCL management concerns and to support the research projects identified in the DCERP Research Plan. During Phase II, results from research projects will feed back into this adaptive Baseline Monitoring Plan so that changes in the frequency and intensity of sampling, spatial scale of sampling locations, or parameters to be sampled can be adapted as necessary. Results from the monitoring and research efforts will be used to identify ecosystem indicators and to develop associated threshold values, tools, or design models that address MCBCL management needs. This information will be communicated to MCBCL to assist in the decision-making process. This information transfer may occur rapidly for some management needs or may require longer periods for the collection of research and monitoring data to provide appropriate indicators, models, or other tools. Once this information is transitioned to MCBCL, the Base’s natural resources managers will be able to make decisions as to what type of management action should be taken and to implement appropriate physical or military operational changes. After the implementation of these changes, the RTI DCERP Team will continue monitoring activities (feedback loop) to ensure that the desired management outcomes are achieved.

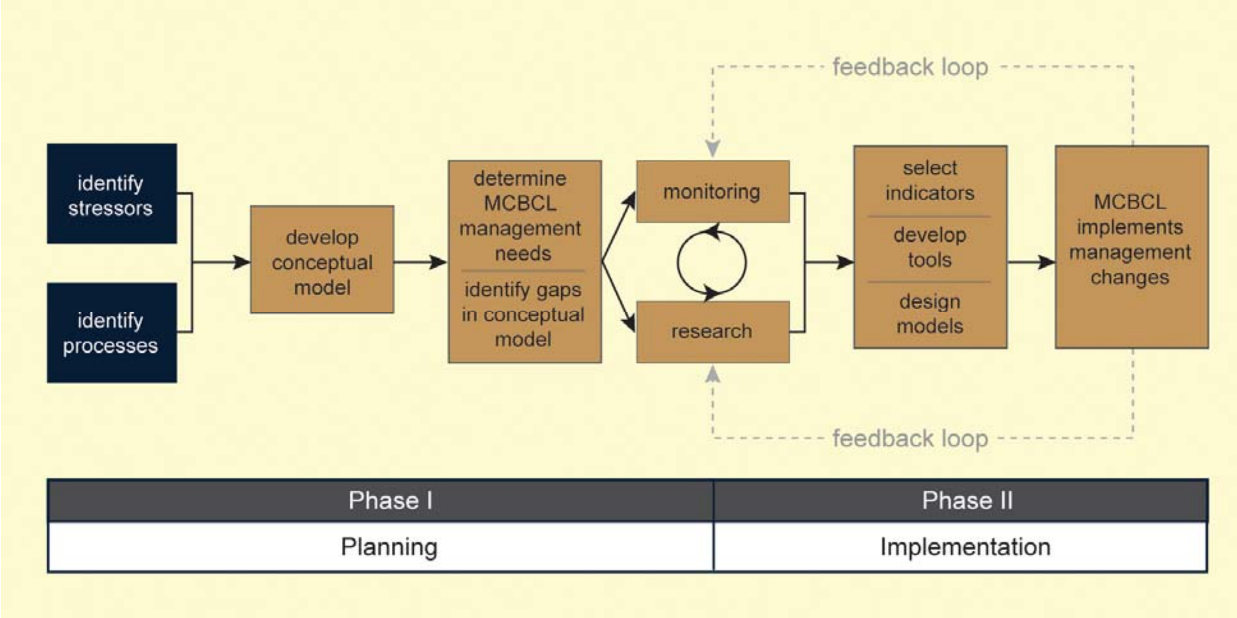


Figure 3-3. DCERP planning and implementation process flow chart.

4.0 Purpose of the Baseline Monitoring Plan

The purpose of the DCERP Baseline Monitoring Plan is to describe the proposed DCERP baseline monitoring program that will be conducted at MCBCL and that will provide an historic reference of selected environmental parameters over the duration of the program. The baseline monitoring data to be collected will include the following:

1. Basic, fundamental parameters that support the broader ecosystem-based research agenda.
2. Parameters that provide data useful to more than one ecosystem module.
3. Parameters that need to be monitored intensively and/or continuously for a long period of time (5–10 years) to determine trends and natural variability.

At the end of DCERP, it is the ultimate goal to transition to MCBCL a scaled-down version of the baseline monitoring program that identifies key measurement parameters for continued monitoring.

This Baseline Monitoring Plan is based on a holistic, ecosystem-based approach to monitoring design. DCERP is designed to monitor environmental status and trends in a multimedia setting and takes into account design objectives, competing time and space demands, candidate technologies, and costs. In conjunction with the research projects, the DCERP monitoring effort will provide the information necessary to develop and test ecosystem models; identify environmental indicators to inform MCBCL natural resources managers about the status of ecosystem health; and guide restoration and conservation efforts. This plan is guided by the principle of gathering systematic, time-series observations on components of ecosystem processes, stressors, and indicators over a period of time sufficient to determine the (1) existing status, (2) trends, and (3) natural variation of measured components.

The baseline monitoring program is seen as an adaptive program, in which monitoring may be adjusted over time in response to weather events, the availability of more efficient methods, and new information gained from ongoing monitoring and research efforts.

4.1 Summary of Monitoring Activities

The conceptual models for each ecosystem have identified numerous knowledge gaps in the understanding of key ecosystem processes, as well as critical Base conservation and water quality management needs. **Appendix B** provides the prioritized list of MCBCL conservation and water quality management needs and identifies how these needs will be addressed. Communication between MCBCL managers and DCERP researchers is critical to the setting of priorities for monitoring activities. An extensive planning process for DCERP (four 2-day meetings over 7 months) provided opportunities for coordination between MCBCL managers and DCERP researchers. The DCERP Module Team Leaders selected monitoring activities for inclusion in this DCERP Baseline Monitoring Plan that fill research needs and address key Base management concerns, with the goal of sustaining military training and natural resource values. **Table 4-1** provides a summary of the module-specific monitoring activities proposed for the four implementation years.

Table 4-1. Summary of Module-Specific Monitoring Activities

Module	Activities
Aquatic/ Estuarine[a]	Hydrodynamics: Stream flow and discharge (New River and tidal creeks) Chemistry: Nutrients, salinity, pH, oxygen, temperature (New River, NRE, and tidal creeks) Sedimentology: Total suspended solids (New River and tidal creeks), turbidity (NRE) Biology: Primary productivity, phytoplankton, fluorescence (NRE)
Coastal Wetlands	Land cover and shoreline erosion: Location and elevation Hydrodynamics: Tide gauges (hydroperiod) Chemistry: Nutrients, salinity, hydraulic conductivity (shallow ground water) Sedimentology: Accretion rates, organic content, particle size
Coastal Barrier	Hydrodynamics: Wave velocity, wave heights/period, currents, shoreline position Meteorology (ocean): Air temperature, wind velocity, barometric pressure, humidity, solar radiation Sedimentology: Compaction, texture, and composition Biology: Benthic invertebrates, shorebirds/seadbirds, dune/shrub/marsh vegetation, sea turtles
Terrestrial	Land cover/land use: Determine changes in land cover/ land use (vegetation types, buildings, roads) and determine military training impacts Biology: Vegetative community assessment, fuel load Soil: Soil bulk density, pH, organic matter content
Atmospheric	Meteorology (air): Wind speed, wind direction, barometric pressure (BP), relative humidity (RH), air temperature, photosynthetically active radiation (PAR), precipitation EPA Criteria Pollutants: Ozone, fine and coarse particulate matter (mass)

[a] Sedimentology, chemistry, and biology of the NRE benthic zone are characterized by Research Project AE-3.

The baseline monitoring program can also be broken down into monitoring components that are general (not module-specific) or module-specific. The general monitoring proposed for DCERP includes several different types of environmental sampling conducted by several modules teams; this sampling will provide data that is vital to a holistic understanding of the Base ecosystems. These general types of monitoring activities collect monitoring data that are useful to all modules and include the following:

1. Land-based and sea-based meteorological data that will be acquired from the U.S. Weather Service, on-site MCBCL meteorological stations, and the Coastal Ocean Research Monitoring Program (CORMP), as well as meteorological data collected by the Atmospheric Module Team.
2. Land cover/land-use data will be acquired from Landsat Thematic Mapper ™, IKONOS, LIDAR, and MCBCL by the Terrestrial Module Team to conduct an analysis of land cover, land-use changes, and military activities.

DCERP has been designed to study linkages among the various ecosystem components. **Table 4-2** identifies which module team will be responsible for collecting selected data and also shows the integrated nature of this Baseline Monitoring Plan by identifying other modules that use this same data. Additional details about the linkages between the various monitoring activities are described in Section 6 (*Module-Specific Baseline Monitoring*).

It should also be noted that the baseline monitoring program proposed by the RTI DCERP Team will include both (1) acquired environmental data collected by another party (e.g., federal or state agency or as part of an existing MCBCL program or MCBCL-funded program) and obtained by the RTI DCERP Team for analysis and (2) sampled environmental data collected onsite at MCBCL by the RTI DCERP Team. The source of environmental data used in all statistical analyses or modeling procedures will be carefully documented by the DCERP Team.

Table 4-2. Monitoring Data Being Collected and Used by Various Modules[a]

Aquatic/Estuarine	Coastal Wetlands	Coastal Barrier	Terrestrial	Atmospheric
New River: flow, discharge, nutrients and sediment	New River: flow and sediment			
Tidal creeks: flow, temperature, nutrients, sediment	Tidal creeks: flow, nutrients, sediment			
NRE (water column): PAR, PP, nutrients, sediment, chlorophyll *a*, phytoplankton	NRE (water column): nutrients, sediment, PP			
Land cover and shoreline erosion	Land cover and shoreline erosion	Land cover and shoreline erosion	Land cover and shoreline erosion	
Marsh surface elevation: tide gauge	Marsh surface elevation: tide gauge	Marsh surface elevation: tide gauge	Marsh surface elevation: tide gauge	
Nutrient flux in marsh ground water	Nutrient flux in marsh ground water			
Hydrodynamics: wave velocity, direction and period, currents	Hydrodynamics: wave velocity, direction and period, currents	Hydrodynamics: wave velocity, direction and period, currents		
Offshore weather data	Offshore weather data	Offshore weather data	Offshore weather data	Offshore weather data
Geomorphology: shoreface bathymetry and barrier morphology	Geomorphology: shoreface bathymetry and barrier morphology	Geomorphology: shoreface bathymetry and barrier morphology		
		Sedimentology: texture, compaction, and composition		
		Biology: benthic invertebrates; surf fish and shorebird; plant cover		
Land use/cover data	Land use/cover data	Land use/cover data	Land use/cover data	Land use/cover data
			Flora: species composition and diversity	
			Forest floor and soils: fuel load, bulk density	

Aquatic/Estuarine	Coastal Wetlands	Coastal Barrier	Terrestrial	Atmospheric
Land-based weather data: wind speed/ direction, BP, RH, PAR	Land-based weather data: wind speed/ direction, BP, RH, PAR	Land-based weather data: wind speed/ direction, BP, RH, PAR	Land-based weather data: wind speed/ direction, BP, RH, PAR, ozone, particulate matter	Land-based weather data: precipitation, wind speed/ direction, BP, RH, PAR, ozone, particulate matter

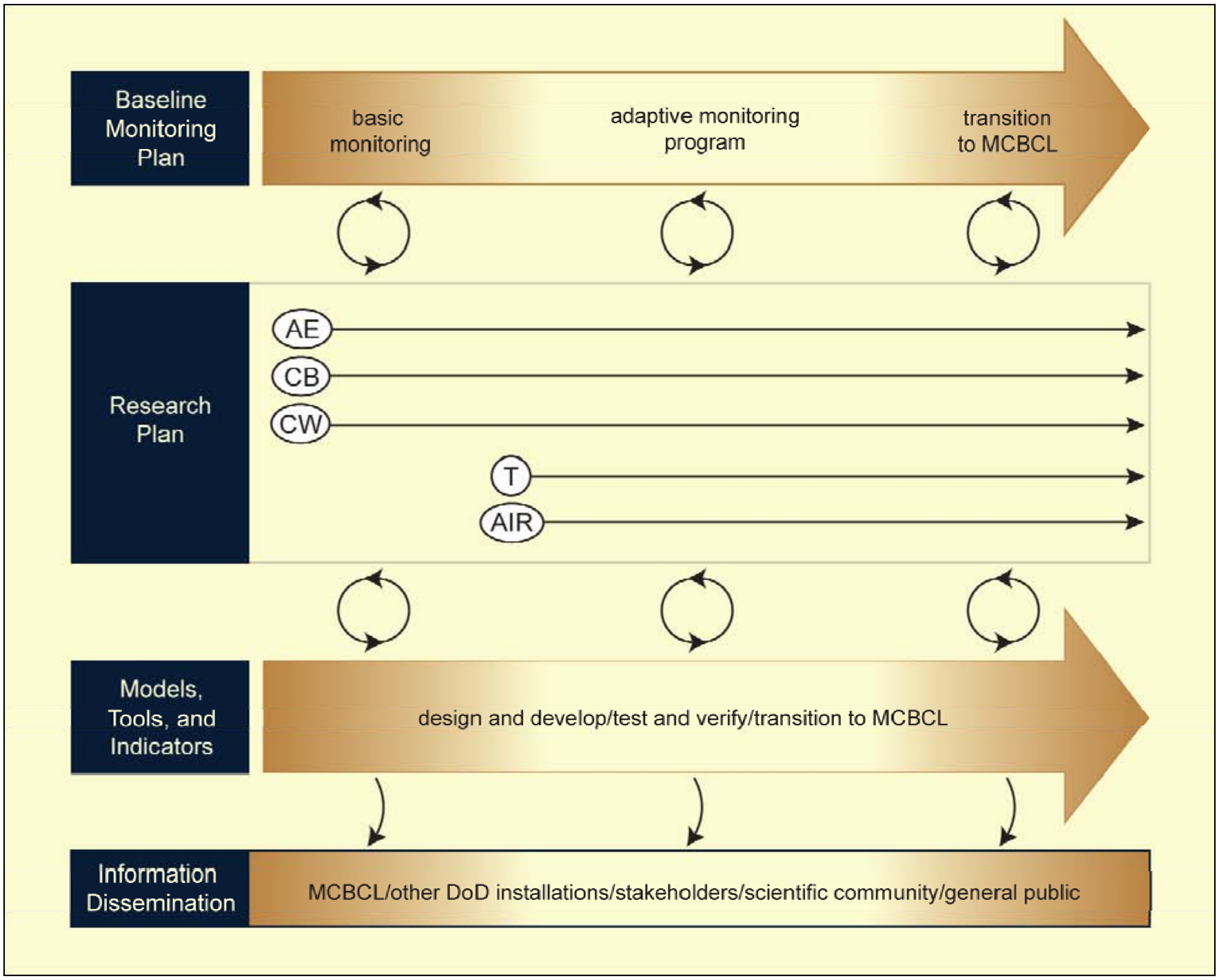
[a] In each row, the blue box identifies the module collecting the data; white boxes indicate modules that will use the data.

4.2 Integrating DCERP Monitoring and Research

Figure 4-1 provides a graphic representation of Phase II (implementation of the Baseline Monitoring and Research plans), as previously identified in **Figure 3-3**. In the DCERP approach, the DCERP Baseline Monitoring and Research plans are closely integrated (as shown by the feedback loops through the duration of DCERP) so that the outcomes of research projects can be used to modify the adaptive baseline monitoring and the monitoring data in turn can provide data for development, and well as refinement and verification of the models, tools, and indicators created as part of the research effort. Again, the models, tools, and indicators will be continuously modified as additional research and/or monitoring data become available.

Research projects will incorporate data from DCERP's baseline monitoring program, MCBCL environmental monitoring activities, and other local, state, federal, and private monitoring activities to provide an integrated approach to ecosystem-based management and to alleviate redundancy in data collection activities. Research projects will not necessarily start at the same time during DCERP, but will be phased to integrate research linkages among the various modules. Schedules and site locations for all DCERP research activities will be coordinated with the selection of baseline monitoring sites to ensure that linkages between the baseline monitoring and research project sampling sites are maintained whenever possible. Information derived from research projects will aid in adapting elements of this DCERP Baseline Monitoring Plan. For example, initial monitoring activities may need to change (i.e., adding or deleting parameters being sampled, increasing or decreasing sampling frequencies of some parameters, or increasing or decreasing spatial extent of sampling locations) in response to results obtained from research projects. In this way, the baseline monitoring program will be adaptive in nature to respond to new information on environmental parameters being monitored.

In addition, **Figure 4-1** also shows how the models, tools, and indicators that are designed, developed, tested, and verified can be transitioned to MCBCL to assist in monitoring and forecasting ecosystem changes. The models, tools, and indicators developed from the research projects also should help to streamline the baseline monitoring to a limited set of key parameters that will be easily transitioned to MCBCL at the end of DCERP. It is a goal of DCERP to disseminated monitoring and research results and information from associated models, tools, and indicators to MCBCL, as well as to other users groups, including other DoD installations in similar ecological settings, the scientific community, other stakeholders (e.g., New River Roundtable or Onslow Bight Conservation Forum) and the general public.



Note: AE = Aquatic/Estuarine Module; CB = Coastal Barrier Module; CW = Coastal Wetlands Module; T = Terrestrial Module; AIR = Atmospheric Module

Figure 4-1. Generic roadmap of the integrated monitoring and research plans and the development of models, tools, and indicators.

Specific roadmaps for each of the five ecosystem modules illustrate the linkages among monitoring and research activities; summarize the models, tools, and indicators that will be developed from these activities; and disseminate information to MCBCL and other stakeholders. These roadmaps illustrate how information from the research projects and outcomes will be used to refine the monitoring activities before these activities are transitioned to MCBCL at the completion of DCERP. The five ecosystem module roadmaps are located in **Appendix E**.

4.3 Other Monitoring and Research Efforts Related to DCERP

The RTI DCERP Team will leverage data from other ongoing monitoring and research efforts. This includes data from MCBCL natural resources managers and other SERDP-funded research being conducted at MCBCL. **Appendix C** provides a list of other monitoring and research activities occurring within the NRE watershed and on MCBCL either funded by MCBCL or conducted by state and local agencies.

5.0 Setting of Camp MCBCL

5.1 Location

MCBCL is located near Jacksonville, NC, approximately 300 miles south of Washington, D.C., and 200 miles north of Charleston, SC. MCBCL encompasses an estimated 142,852 acres, of which 18,370 acres (12%) is water. The Base is located entirely within Onslow County, NC, approximately 45 miles south of New Bern, NC, and 47 miles north of Wilmington, NC. The City of Jacksonville is the county seat and the primary commercial center for MCBCL. According to the INRMP (MCBCL, 2006a), MCBCL is the USMC's largest amphibious training base and is home to 47,000 Marines and sailors; the largest single concentration of Marines in the world. A brief description of ongoing military operations at MCBCL is located in **Appendix A**.

5.2 Ecoregion

MCBCL is located in the Atlantic Coastal Flatlands Section of the Outer Coastal Plain/Mixed Forest Province (**Figure 5-1**) (Bailey et al., 1994). Based on similar regional climate, geologic origin, topography, drainage networks, and potential natural vegetation, this section has the following characteristics:

- Stratified marine deposits that were formed during the Cenozoic Era (66 million years ago to the present)
- Utisol and Spodosol soils that are deep, medium textured, and have adequate to excessive water supplies for vegetation
- Small- to medium-sized perennial streams, few associated rivers, and a high water table in many areas, leading to poor natural drainage and many wetland areas
- Southern mixed pine and oak/hickory/pine forests, with smaller areas of floodplain forests and pocosins
- Fire as the predominant natural disturbance; frequent hurricanes and insect activity are also natural stressors
- Land elevations ranging from 0–80 feet above mean sea level
- Average precipitation of 46 inches per year, average temperature of 55–57 °F, and a growing season of 185 to 220 days.

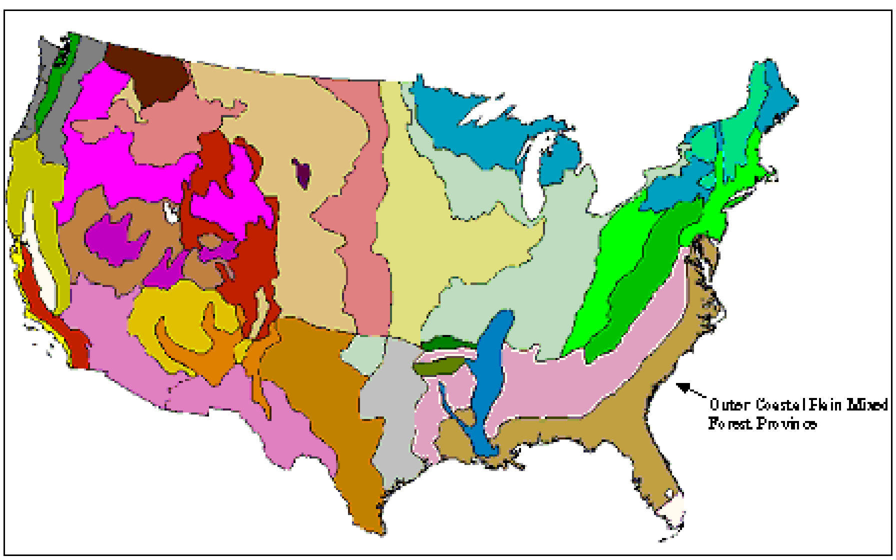


Figure 5-1. Bailey's ecoregions (Bailey et al., 1994).

5.3 Water Resources

5.3.1 Tributaries

Approximately 17 miles of streams are found within the boundaries of MCBCL, and these waters flow into the NRE, ICW, or Northeast Cape Fear River. The majority of MCBCL drains into the NRE and is comprised of approximately 162 stream miles. The New River, its tributaries, and several small coastal streams, as well as the ICW, comprise the U.S. Geological Survey (USGS) Hydrologic Unit Code (HUC) 03030001 and North Carolina Division of Water Quality (NCDWQ) Subbasin 03-05-02 (NCDWQ, 2001; 2001).

A small, eastern portion of the Base drains directly into the ICW (or Bear Creek and Queens Creek, which flow directly to the ICW) and is comprised of approximately 15 stream miles. This area is categorized as USGS HUC 03020106 and NCDWQ Subbasin 03-05-01 (NCDWQ, 2007).

The majority of the Greater Sandy Run Area (GSRA), located in the western portion of MCBCL, flows into the Northeast Cape Fear River and is comprised of 44 stream miles. This area is categorized as USGS HUC 03030007 and NCDWQ Subbasin 03-06-23 (NCDWQ, 2005).

5.3.2 New River Estuary

The New River watershed encompasses 462 mi^2 and is located entirely within Onslow County. The NRE is a broad, shallow, periodically vertically stratified estuary with a surface area of 34 mi^2 (NOAA, 1999). MCBCL also encompasses 16,650 acres of the NRE and 1,720 acres of the ICW (MCBCL, 2006a). The volume of the NRE is estimated at 170 million cubic yards and has an estimated mean flushing time of 70 days (ranging from 8 to 187 days [Ensign et al., 2004]). This study found shorter flushing times in the winter months (November – March), when freshwater inflow is higher, and longer flushing times in the summer months (May – October), when freshwater inflow is lower. Tidal exchange at the mouth of the NRE is restricted at the New River Inlet and likely contributes to the long flushing time and semi-lagoonal nature of this system.

The NRE is used for commercial and recreational fishing, bathing, and military operations in delineated areas. It has a history of nutrient-driven eutrophication, harmful algal blooms (HABs), and hypoxia, with associated impacts on water quality and habitat (Mallin et al., 1997; 2005). In large part, the semi-lagoonal characteristics of the NRE make it susceptible to nutrient over-enrichment and eutrophication. Recent efforts to reduce eutrophication by improving wastewater treatment of nutrients (nitrogen [N] and phosphorus [P]) have helped improve water quality, but anticipated increases in population and development in the NRE watershed and on the Base are likely to increase the nutrient and sediment loads to the estuary.

5.4 Topography and Soils

MCBCL (excluding the GSRA) is characterized by a combination of poorly drained, broad, level flatlands and gently rolling, better-drained terrain. East of the New River, the flatlands range in elevation from 25 to 45 feet above mean sea level. West of the New River, the changes in elevation are more pronounced, with three areas reaching 72 feet above mean sea level (MCBCL, 2006a). Approximately 30% of the soils are classified as hydric (wet), with the most common being Leon fine sand, Muckalee Loam, and Murville fine sand. Common non-hydric soils include well-drained Baymeade fine sand and the moderately well-drained Marvyn loamy fine sand and Onslow loamy fine sand (SCS, 1992).

In the GSRA of MCBCL, the land is almost uniformly flat and poorly drained. Elevation ranges from 39 to 69 feet above mean sea level, with the greatest variation in elevation in the eastern-most portion of the GSRA, which drains into the New River (MCBCL, 2006a). Seventy-five to 80 percent of the soils are

classified as hydric (wet), including Croatan Muck, Leon Fine Sand, Muckalee Loam, Murville Fine Sand, Pantego Mucky Loam, Rains Fine Sandy Loam, Torhunta Fine Sandy Loam, and Woodington Loamy Fine Sand (SCS, 1992). The remaining non-hydric soils, which are more suitable for road and facility development, are most common along the western side and in the northeastern corner of the GSRA.

5.5 Geology

As glacial events and slight crustal movements have altered sea level measurements over the past 66 million years, the land base has been alternately exposed and submerged. Marine deposits laid down over time on this land base formed the weakly dissected alluvial plain that MCBCL occupies today. These deposits are mostly clean sand and clayey sand, layered with deposits of clay and marine shells. Along the coast, stream sediment deposition and natural shore processes develop and maintain beaches, swamps, and mud flats.

Three primary geomorphic surfaces are identified at MCBCL (MCBCL, 2006a):

- ***Pamlico surface***. Elevations of 0 to 25 feet above mean sea level in narrow strips along the ICW (along the southeast border of the Base) and the New River and its tributaries.
- ***Wicomico surface***. Elevations of 45 to 75 feet above mean sea level found in a few areas south of Jacksonville.
- ***Talbot surface.*** Elevations of 25 to 45 feet above mean sea level underlying most of MCBCL.

5.6 Climate

Onslow County, NC, has a warm, temperate climate. The county seat, Jacksonville, NC, averages 56 inches of rainfall a year. The rainfall is almost evenly distributed throughout the year, with a slight increase from June through September. The growing season, with daily minimum temperatures higher than 28 °F for 5 years out of 10, is 235 days long (March 19 – November 11). Thunderstorms occur approximately 45 days a year. Prevailing winds are from the southwest in the summer and from the northwest in the winter. The average annual wind velocity is approximately seven knots (MCBCL, 2006a).

5.7 Vegetation

MCBCL encompasses approximately 92,300 acres of forest, including 47,734 acres of pure pine, 21,985 acres of pure hardwood, and 22,596 acres of mixed pine/hardwood stands. An additional 17,328 acres are non-forested, and 12,543 acres fall within impact areas (MCBCL, 2006a). Loblolly is the most common pine species, accounting for approximately 75% of timber on the Base, and blackgum is the most common hardwood. Fire plays a deciding role in the communities of MCBCL, affecting canopy and understory density and species composition.

MCBCL contains some of the highest-quality longleaf pine and pocosin habitat in North Carolina, as well as high-quality examples of pine savanna, wet pine flatwoods, and small depression ponds (limesinks). MCBCL contains numerous sites of significant natural heritage areas, including 2 coastal sites (Browns Island and New River Inlet), 1 coastal edge site (Corn Landing), 1 inland tidal site (Southwest Creek), and 27 inland sites (NCNHP, 1999).

5.8 Demographics

The 2000 U.S. Census Bureau provides demographic information for both Onslow County and MCBCL. In 2000, the population of Onslow County was 150,355. Included in this figure are 34,452 residents of MCBCL. The 2000 U.S. Census indicates a slight (0.3%) increase in the population of Onslow County and a significant decrease (31%) in the population of MCBCL since 1990. This is due, in part, to

downsizing throughout the military, with a 12% decrease in USMC personnel. More detailed information regarding the demographics of Onslow County and the State of North Carolina can be found on the World Wide Web at www.census.gov and at www.quickfacts.census.gov.

5.9 Military Land Usage

A map of MCBCL depicting levels of accessibility (**Table 5-1**) and a preliminary analysis of training usage is located in **Appendix D**. This map was use by module teams for preliminary selection of monitoring sites to reflect a potential range of training uses and to indicate areas not accessible for monitoring activities (such as Impact Areas).

Table 5-1. Summary of MCBCL Restricted Access Areas

Level of Accessibility	Definition
Areas not available for monitoring	These are impact areas (N1-BT3, G-10, K-2) and are off limits. High explosives are used in these areas, and unexploded ordnance are present. Also included in this category is the Marine Special Operations Command (MARSOC) located in Stone Bay.
Areas with current or future limited accessibility	These areas are live-fire ranges and, while in use (“hot”), are not accessible. Because only non-explosive munitions are used in these areas, they are available to researchers for use, but do require advanced scheduling to gain access. Live-fire ranges are represented by surface danger zones that are in the shape of a cone. Surface danger zones include the firing point, target area, and buffer area for stray munitions.
Housing/cantonment areas	These areas are available for monitoring, but do require scheduling. Because these areas are primarily military housing, scheduling is required to minimize potential conflicts and to respect private housing areas.

The training area classifications provided in **Appendix D** designed to provide a preliminary, rough estimate of military use levels across the Base, on a scale from highest to lowest use. This use level was developed using the number of scheduled non-live fire training events in a training area over the course of one year. However, these numbers can be misleading because more than one event can be scheduled for an area, so the number of events can exceed 365. For example, two different units could be recorded in the database as having the same number of men in the unit, with each unit using 10 vehicles, but one unit is doing light infantry maneuvers with most of the training on foot (i.e., the impact is minimal), whereas the other unit may be driving throughout the training area (i.e., the impact is greater). A DCERP research project will be conducted during the first year of Phase II to better classify military training impacts at MCBCL.

6.0 Module-Specific Baseline Monitoring

The following sections contain the proposed baseline monitoring activities for each of the five ecological modules (Aquatic/Estuarine, Coastal Wetlands, Coastal Barrier, Terrestrial, and Atmospheric), including background information on the module, the knowledge gaps in the conceptual model that the monitoring data will fill, and the individual monitoring activities that are proposed for implementation. Specific information is provided for each activity, such as the objectives; methods; data analysis and outcomes; relevance to MCBCL; and linkages within the module and among the other modules for each of the four implementation years.

6.1 Aquatic/Estuarine Module

6.1.1 Introduction

Estuaries integrate inputs from terrestrial, freshwater, oceanic, and atmospheric systems (Day and Kemp, 1989; Valiela et al., 1997; Hobbie, 2000), and the accurate assessment and management of estuaries

necessitates consideration of their connections to, and interactions with, these other systems. Estuaries also exist in regions of rapidly expanding and diversifying human activity (Nixon, 1995; Boesch et al., 2001; Cloern, 2001). In the context of the MCBCL region, the Aquatic/Estuarine Module will examine the tidal reach of the NRE from the freshwater head of the New River near Jacksonville, NC, to the tidal inlet at Onslow Bay (see **Figure 1-1**). Understanding and sustaining the function of the NRE cannot occur without quantifying and distinguishing natural processes from human-influenced watershed- and airshed-based impacts, as well as human activities that occur in the estuary (Nixon, 1995; Paerl, 1997; Malone et al., 1999; Boesch et al., 2001) (see **Figure 6-1**). Our monitoring design reflects the level of complexity and integration that exists in natural coastal systems. Aquatic/Estuarine monitoring will be closely coupled to the research activities within this module. Additionally, coordination and information exchange will occur with the monitoring and research activities for the Coastal Wetlands, Atmospheric, Terrestrial, and Coastal Barrier modules, as described in this document and as detailed further in the DCERP Research Plan.

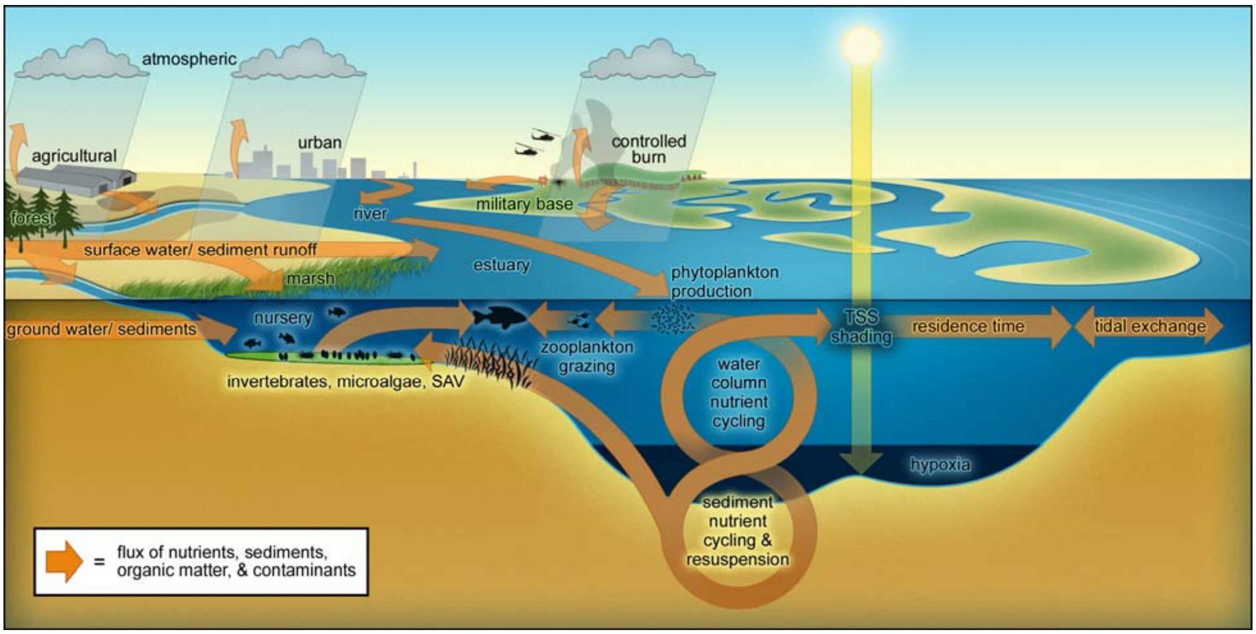


Figure 6-1. Conceptual model for the Aquatic/Estuarine Module.

Estuarine responses to physical, chemical, and biological processes may serve as indicators of ecological change (NRC, 2000; Cloern, 2001; Peierls et al., 2003; Niemi et al., 2004). Inputs of nutrients, sediments, organic matter, and contaminants reach the NRE from multiple sources, including watershed inputs, precipitation and dry deposition from the atmosphere, and tidal exchanges with Onslow Bay. Watershed inputs include sources from the New River at Jacksonville, NC; creeks that drain into the NRE; surface runoff; and ground water as baseflow. These inputs influence the biological and chemical cycling within the NRE's water column and sediments (e.g., nutrient cycling and sediment transport) (Cloern, 2001; Anderson et al., 2003). Nutrients stimulate both phytoplankton and benthic microalgae (primary production), thereby providing food for zooplankton and benthic invertebrates (secondary production), respectively (Hobbie, 2000; Sundbäck et al., 2003). The zooplankton and benthic invertebrates provide food for fish, and phytoplankton is the primary food source for shellfish. An overgrowth of phytoplankton and excessive sediment inputs, however, can reduce light penetration, leading to declines in important nursery area attributes, such as submerged aquatic vegetation (SAV) and benthic microalgal abundance (Gallegos et al., 2005), thereby reducing the food supply for benthic-feeding fish. Additionally, excessive amounts of phytoplankton (e.g., algal blooms) sink from surface to bottom waters within the estuary and, together with watershed inputs of organic matter, lead to depleted oxygen conditions (hypoxia or anoxia)

in bottom waters. Such hypoxic and anoxic events can have critical negative impacts on shellfish, other invertebrates, and finfish (Paerl et al., 1998; Rabalais and Turner, 2001). These processes may be influenced by water exchanges with Onslow Bay, which have the potential to remove excess nutrients, organic matter, and phytoplankton. The NRE's response to natural and anthropogenic impacts depends in part on physical and biological interactions, such as wave activity, which leads to the resuspension of bottom sediments, and freshwater discharge and exchange, which affects the estuary's water residence time and degree of stratification (Luettich et al., 2000). These conditions strongly influence the biomass and composition of the autotrophic communities within the NRE, the estuary's susceptibility to hypoxia/anoxia, and the importance of microbial processes that control cycling of nutrients and organic matter between the water column and benthos.

6.1.2 Monitoring Objectives and Activities

The Aquatic/Estuarine Module monitoring program summarized in **Table 6-1** is designed to (1) improve the understanding of the complex interacting physical, chemical, and biotic processes that drive water, sediment, and habitat quality; (2) support the research components; (3) differentiate natural from anthropogenic ecosystem forcing mechanisms, including consideration of extreme events such as hurricanes, nor'easters, floods, and droughts; (4) provide information for designing and implementing a long-term monitoring program that ensures compatibility of Base activities with desirable estuarine water, sediment, and habitat quality; and (5) facilitate conservation of regional natural resources for ecosystem, recreational, and economic benefits. The monitoring component is adaptive and will be adjusted in response to the availability of more effective and efficient indicators, methods, and new information gained from the research components.

Table 6-1. Aquatic/Estuarine Module Monitoring Components

Area	Variable	Spatial Scale	Temporal Scale
New River	Stream flow and discharge	New River at Jacksonville	Continuous
	Nutrients and sediment	New River at Jacksonville	Monthly (outgoing tide)
	Water temperature, dissolved oxygen (DO), pH, salinity	New River at Jacksonville	Monthly in addition to nutrient/sediment sampling
Tidal Creeks	Water level (stream flow) and temperatures	8 stations (paired)	Continuous
	Nutrients (dissolved inorganic nitrogen [DIN], dissolved inorganic phosphorus [DIP], dissolved organic nitrogen [DON], total nitrogen [N], and total phosphorus [P]), total suspended solids (TSS), fecal indicator bacteria (FIB)	8 stations (paired)	Monthly (base flow); Episodic (storm flow)
New River Estuary - Water Column	Fluorescence (chlorophyll *a*), colored dissolved organic matter [CDOM]), DIN, N, DIP, P, TSS	8 stations (6 vertical profiling and 2 continuous autonomous vertical profilers [AVPs]) - longitudinal from New River to Inlet	Monthly for profiles and data flow, year-round for AVPs; more intensive (March–Oct)
	Photosynthetically active radiation (PAR), salinity, water temperature, DO, pH, turbidity, flow, precipitation	8 stations (6 vertical profiling and 2 continuous AVPs) - longitudinal from New River to Inlet.	Monthly for profiles and data flow, year-round for AVPs more intensive (March–Oct)

Area	Variable	Spatial Scale	Temporal Scale
	Primary productivity (PP), chlorophyll-*a* by fluorometry and high performance liquid chromatography (HPLC), phytoplankton pigments/counts	8 stations (6 vertical profiling and 2 continuous AVPs) - longitudinal from New River to Inlet	Monthly for profiles AVPs and data flow

Note: The benthic zone of the NRE will be characterized by Research Project AE-3. See the DCERP Research Plan.

Table 6-2 summarizes the estimated level of effort for each of the key personnel during the first four years of Phase II for the monitoring activities previously listed in **Table 6-1**. A specific list of the personnel for each monitoring activity is located within the Methods section of each monitoring activity described in Section 6.1.4 (*Aquatic/Estuarine Module Monitoring Components*).

Table 6-2. Aquatic/Estuarine Module's Estimated Staffing of Monitoring Activities

Personnel	Time in months/year			
	Year 1	Year 2	Year 3	Year 4
Hans Paerl	1	1	1	1
Mike Piehler	0.5	0.5	0.5	0.5
Rick Luettich	0.5	0.5	-	-
Jerad Bales	0.5	1	1	1
Graduate Student (1)	12	12	12	6
Undergraduate Student (1)	4	4	4	4
Technicians (3)	22	22	19	9

6.1.3 Benefit to MCBCL

To ensure the continued function of the NRE, MCBCL must consider means to maintain and enhance estuarine biotic integrity, while maintaining and enhancing training opportunities. Satisfying the terms of the CWA is also of central interest, including management to avoid the imposition of Total Maximum Daily Loads (TMDLs) and maintaining National Pollutant Discharge Elimination System (NPDES) permits and abide by the CWA. Like all stakeholders in coastal waters, MCBCL has responsibilities for the NRE, which has been designated as nutrient-sensitive by North Carolina Department of Environment and Natural Resources (NCDENR). MCBCL also has responsibility for meeting stakeholder water quality requirements for the NRE to support recreational and commercial uses of the system. The Aquatic/Estuarine Module's research plan includes quantification of watershed loading of freshwater; loading of sediment, nutrients, and fecal coliform bacteria; deployment of autonomous vertical profilers to study water column structure and quantify currents; development of water column algal indicators (including harmful species).

6.1.4 Aquatic/Estuarine Module Monitoring Components

6.1.4.1 New River

6.1.4.1.1 Objective(s)

The USGS currently monitors streamflow on the New River near Gum Branch (Site 1 in **Figure 6-2**). This site will continue to be monitored during the project at no cost to DCERP. An additional stream gage is needed at the head of the NRE near Jacksonville (Site 2) to account for the total input of freshwater, sediments, and nutrients to the estuary from the upstream watershed.

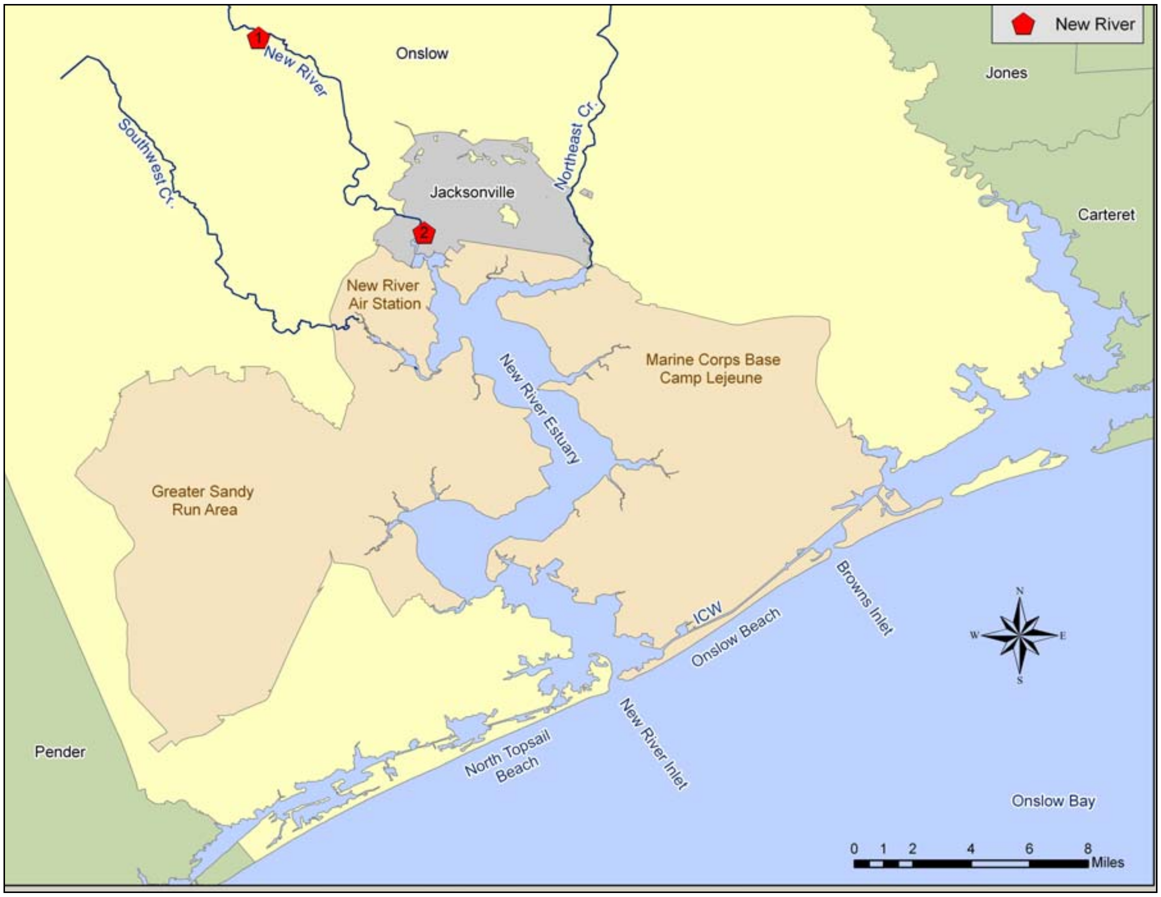


Figure 6-2. New River monitoring stations.

6.1.4.1.2 Relevance to the Base

These data will provide information regarding local and regional water quality to avoid actions under the CWA. Input to the NRE from the upstream watershed is needed to distinguish the effects of inputs from the Base and inputs from the watershed on estuarine water quality.

6.1.4.1.3 Scale

Regional scale. This site provides information on inputs of freshwater, nutrients, and sediment from the entire New River to the New River Estuary.

6.1.4.1.4 Linkages within the Module and among other Modules' Monitoring Components

These activities will be directly linked to other Aquatic/Estuarine monitoring activities in this module as New River inputs of freshwater and materials – and interannual variations and extreme events – will exert a fundamental control on all the parameters being monitored in the NRE, and thus will aid in the interpretation of this monitoring data. The proposed sites are the upstream-most sites in the monitoring program. Delivery of nutrients and sediments from creeks to the estuary downstream from this site must be separated from inputs from the upstream watershed in order to distinguish effects of Base activities from other upstream activities on estuarine water quality. Groundwater withdrawals may also affect freshwater inflows, resulting in a change in salinity and aquatic habitat. Lastly, New River nutrient input data will be compared and synthesized (in terms of determining short-term [event-scale] and long-term

[seasonal annual] loading estimates) with atmospheric, shallow ground water and stream nutrient inputs being measured by the Atmospheric, Terrestrial, Aquatic/Estuarine and Coastal Wetlands modules.

6.1.4.1.5 Methods

Spatial/Site Locations

Figure 6-2 illustrates the existing streamgaging site and the proposed new site. The existing streamgage (Site 1) is located on the New River near Gum Brach and will continue to be monitored at no cost to DCERP. The USGS station number for Site 1 is 02093000. The new streamgage (Site 2) will be located on the New River near Jacksonville and its purpose is to capture inputs of freshwater, nutrients, and sediment to the estuary from upland sources.

Temporal Considerations

Streamflow and river stage will be monitored continuously. Periodic measurements of tidal flow will be made in order to calibrate the streamgage. Nutrients and sediment samples will be collected 15 times per year on outgoing tides. Samples will be analyzed for suspended sediment (TSS), dissolved nitrate, dissolved ammonia, total organic nitrogen (TON), total phosphorus, and dissolved ortho-phosphorus, and total organic carbon (to be done at University of North Carolina Institute of Marine Science [UNC-IMS]). Vertical profiles of temperature, DO, pH, and salinity will be made at least monthly, and each time a sample is collected.

Personnel

- Senior Researcher: Jerad Bales
- Technicians: Various hydrologic technicians trained in tidal discharge measurement and computation and in clean sampling techniques.

Parameters/Variables

- Streamflow
- Water surface elevation
- Suspended sediment
- Dissolved nitrate
- Dissolved ammonium
- Total nitrogen
- Total phosphorus
- Dissolved ortho-phosphorus
- Total organic carbon
- Water temperature
- Dissolved oxygen
- pH
- Salinity

Field and Laboratory Procedures

Sampling Design and Collection. Standard USGS methods will be used for all data collection, processing, and archiving. Tidal streamflow data collection methods are documented by Morlock et al. (2002), Oberg et al. (2005), Ruhl and Simpson (2005), and Simpson (2002). Procedures for collection of water-quality samples and measurement of field properties are given by USGS (1997–1999) and Horowitz et al. (1994).

Equipment Used.

Field:

- A pressure transducer will be used to measure water level.
- Boat-mounted RDI Acoustic Doppler Current Profiler (ADCP) to measure streamflow (already available)
- Sutron satellite radio to transmit streamflow and water level data to internet and database.
- Standard USGS depth integrating sediment sampler for sample collection (already available).
- Teflon churn splitter and vacuum pump for sample preparation (already available).
- Yellow Springs Instruments, Inc. (YSI) 6600 multi-sensor sondes for measurement of vertical profiles of physical properties (already available).

Laboratory:

- Nutrient and organic matter samples will be analyzed at the UNC-IMS. A listing of equipment is provided under Section 6.1.4.3.5.

Data Management

Standard published USGS protocols will be followed in all data collection. These protocols include collection of duplicate and split water quality samples, and the use of clean methods to prevent sample contamination (USGS, 1997–1999; Horowitz et al., 1994). In addition to national protocols, the USGS in North Carolina has an internally published quality-assurance plan that includes all aspects of project management and data collection. Continuous data transmitted by satellite radio will be reviewed daily. Results from chemical analyses are reviewed regularly and stored in the USGS National Weather Information System (NWIS) database. Scientific investigations are reviewed by Water Science Center teams 3 times per year. The USGS North Carolina Water Science Center participates in a number of national quality-assurance programs, and staff for this project will have adequate technical and safety training.

6.1.4.1.6 Data Analysis, Products, and Outcomes

Continuous records of discharge will be computed from records of water level and velocity measured at the monitoring site. Data will be available for all partners via the USGS Web site. Discharge and tide data will be useful for placing estuarine samples and measurements in the appropriate tidal context. Moreover, samples can be placed in the appropriate hydrologic context (high freshwater inflow, low flow).

Nutrient and sediment samples will be used with discharge to develop loading relations. These relations will then be used along with continuous discharge records to compute daily loads of nutrients and sediment being transported into the estuary. Procedures for computing loads are given by Cohn (2005) and Runkel et al. (2004).

Inputs of freshwater, nutrients, and sediment to the NRE are critical to understanding effects of Base activities on water quality. Without these estimates of upstream inputs, there is no way to distinguish the effects of Base activities from other effects.

6.1.4.2 Tidal Creeks

6.1.4.2.1 Objective(s)

We will measure stream flow and nutrient and sediment concentrations in eight coastal creeks to estimate loading to the NRE. We will relate stream flow to precipitation intensity, duration and frequency data provided from meteorological monitoring. Creek sampling stations will be spatially stratified to assess variability within the estuarine salinity zones and to determine the effects of on land activities on stream

flow, and sediment and nutrient delivery to the estuary. Flow and loading of sediment and nutrients will be related to land use to link land activities and aquatic and estuarine ecosystem function.

6.1.4.2.2 Relevance to the Base

These data will provide information regarding local and regional water quality to avoid actions under the CWA Section 305(b). Data comparing sites with and without military training activity and with varying degrees of impervious surfaces will gauge MCBCL impacts on creek function and will provide information for decision making regarding future building and locations of training. An empirical understanding of the quantity of nutrients and suspended material in coastal streams and some information about its origin will be of significant value for decisions ranging from water quality remediation to shoreline stabilization. Suspended material can impair ecological function through light attenuation and smothering of benthic communities, but it also can enhance ecological function of coastal wetlands through provision of organic matter for accretion.

6.1.4.2.3 Scale

Regional scale. Sites are stratified throughout the region and are paired to capture the effects of various military operations. Four paired locations (8 sites total) will be sufficient to not only provide information about effects of military use, but to also make generalizations about regional coastal creek function within the estuarine gradient.

6.1.4.2.4 Linkages within the Module and among other Modules' Monitoring Components

These activities will be directly linked to other Aquatic/Estuarine monitoring activities in this module by providing loading rates of sediments and nutrients to the NRE. Delivery of nutrients and sediments from creeks to the estuary is an important materials transport mechanism and is often affected by changes in on-land activities. This monitoring activity will also be linked to the Coastal Wetlands Module. For marshes, suspended solids are beneficial rather than detrimental and provide material for accretion. The ability of many marshes to maintain their elevation is dependent upon a supply of suspended sediments. The tidal creek monitoring sites include creeks in the mesohaline and back-barrier (**Figure 6-3**), where the Coastal Wetlands Module will be measuring elevation changes in marshes. Linking these elevation measurements to the creek's sediment supply will be an important step toward understanding mechanistic links between watershed activities and marsh sustainability. These monitoring activities will also be linked to the Terrestrial Module. The stream sampling sites represent an integration of the effects of watershed processes on the load of nutrients, sediments and FIB transported from the landscape. Finally, this monitoring will be integrated with the data collected by the Atmospheric Module in that precipitation will drive stream discharge and deposition of N may be an important contributor to stream N loading.

6.1.4.2.5 Methods

Spatial/Site Locations

The tidal creek monitoring sites are distributed throughout the estuarine salinity gradient and are representative of MCBCL land uses (e.g., industrial, forested, urban [non-industrial]). All creek monitoring stations will be sited above the range of tidal influence. The sites are illustrated in **Figure 6-3** and are identified as follows:

1. Back-barrier - Freeman Creek (Site 10), Gillets Creek (Site 9)
2. Polyhaline - Traps Creek (Site 7), Chadwick Bay (Site 8)
3. Mesohaline - French Creek (Site 6), Town Creek (Site 5)
4. Oligohaline - Wilson Bay (Site 3), Southwest Creek (Site 4)

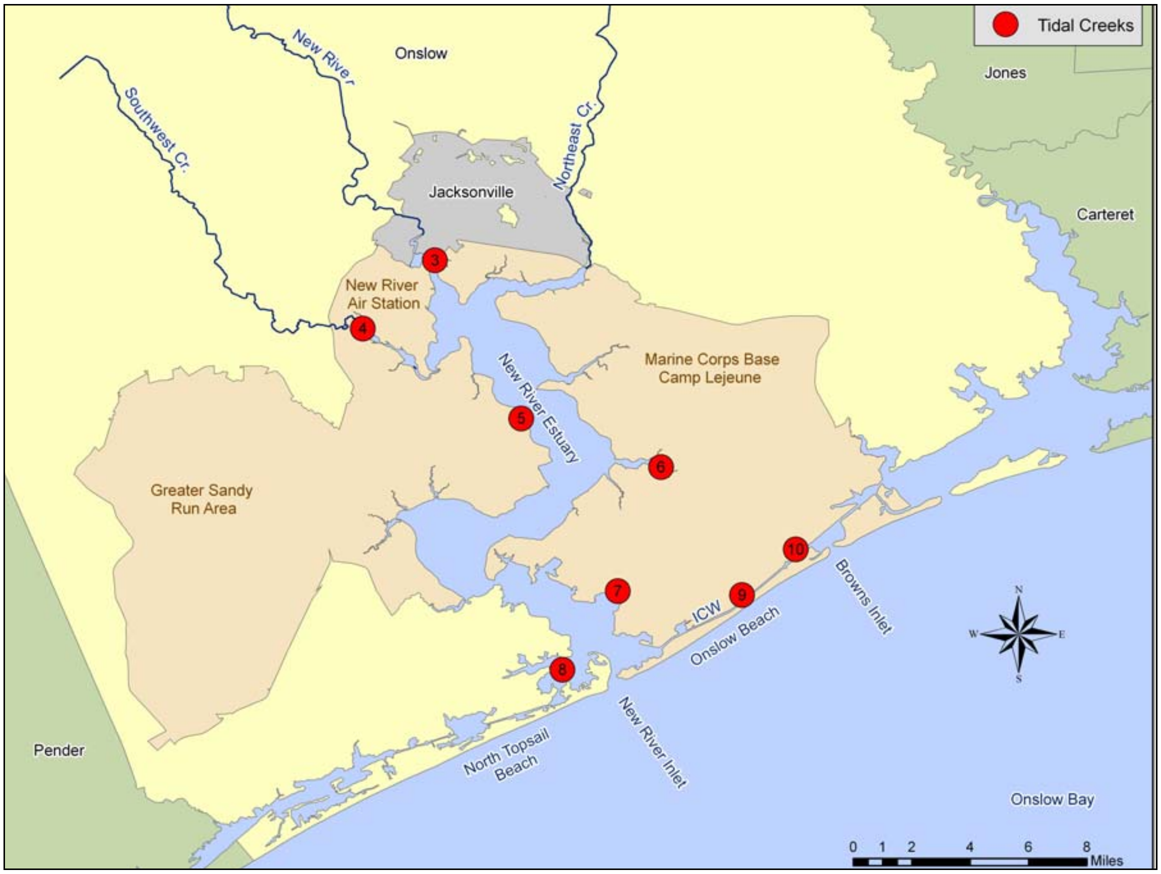


Figure 6-3. Tidal creek monitoring stations.

Temporal Considerations

Routine and episodic monitoring will be included in the tidal creek monitoring. Physical parameters (water level, water temperature) will be measured continuously and water samples will be taken monthly for chemical and suspended material analysis. Episodic (event scale) variability will be assessed by seasonal (4 times per year), storm event sampling.

Personnel

List all the people who will perform this activity.

- Senior Researcher: Mike Piehler
- Technician: (1)

Parameters/Variables

Water level, water temperature, inorganic and organic nitrogen concentrations, inorganic and organic phosphorus concentrations, TSS, and FIB (data from Research Project AE-2).

Field and Laboratory Procedures

Sampling Design and Collection. Water level and temperature recorders will be deployed at each creek. Continuous creek level data will be utilized with channel geometry and several other parameters in the Manning Equation to assess creek velocity.

$$V = \frac{1}{n} R_h^{\frac{2}{3}} \cdot S^{\frac{1}{2}}$$

Where:

V = cross-sectional average velocity (m/s)
n = Manning coefficient of roughness
R_h = hydraulic radius (m)
S = slope of pipe/channel (m/m)

Grab samples will be taken from each creek monthly at base flow conditions and once per season (4 times per year at each creek) during storm flow.

Equipment Used. Level and temperature recorders (YSI, Inc.) will be deployed in stilling wells that will be installed in the creeks upstream of the zone of tidal influence. Nutrients will be analyzed on a Lachat nutrient autoanalyzer and particle suspensions will be quantified gravimetrically.

Equipment will be monitored routinely and information will be obtained on performance in conjunction with each use of the equipment. This information will be stored in log books kept with each piece of equipment. The information will be reviewed weekly by the staff and monthly by the Senior Researcher. Maintenance of equipment used in this project is the responsibility of the Senior Researcher. The technician is responsible for routine maintenance and minor repairs. UNC-IMS maintenance staff will perform appropriate in-house repairs and manufacturer repair experts will be used to perform the remaining repair activities. Records of all significant preventative maintenance activities will be kept with the instruments.

Data Management

Data downloaded from loggers will be checked by technical staff. Laboratory notes and data will be recorded daily in bound laboratory notebooks. Information entered into notebooks from machine printouts will be verified twice and the originals will be filed. Data entered from notebooks into computer files will be verified and validated. This operation will be repeated until two consecutive verification checks yield no errors. Two copies (backup and original) will be kept of all computer files at all times.

6.1.4.2.6 Data Analysis, Products, and Outcomes

Concentrations of inorganic and organic nutrients and measures of particle suspensions from grab samples will be used in conjunction with the velocity measurements to estimate loading of those materials. Loading rates will be directly applicable to the ecosystem model for the region for calibration and validation of land-use specific rates. Additionally, the suspended sediment loads will be applicable to marsh elevation modeling as they represent an important part of the source term for marsh sediment trapping.

When appropriate, data will be subjected to statistical analyses, including time series analyses of flow and loading and comparisons of mean storm- and base flow-loads of sediment and nutrients. Seasonal comparisons will be made within and among sites. Errors will be detected by abnormally high coefficients of variation between replicates. If high variability continues to be observed this will indicate a problem in materials used in the analysis or procedures followed by the personnel. Should this arise, an immediate and thorough review of materials and procedures will be conducted by the Senior Researcher and appropriate changes made.

Creek nutrient and sediment loads can be highly variable and are not easy to compare on broad spatial scales. We will rely on internal indicators of desired condition by calculating loads in relatively un-

disturbed creeks and comparing them to more disturbed creeks based on land cover and land use. Because we are also interested in sediment load as a positive feedback to marshes, we will assess thresholds for minimum sediment loading required to support marsh accretion.

6.1.4.3 New River Estuary – Water Column Chemistry

6.1.4.3.1 Objective(s)

We will monitor the input, distribution, utilization, cycling and fate of nutrients, sediments and other chemical inputs (i.e., contaminants) affecting the productivity, trophic state, water quality and habitat condition of the NRE. Sampling locations will be stratified to assess variability within the estuarine salinity zones, tidal and mixing regimes. These locations allow us to examine links to terrestrial, atmospheric, wetland and oceanic inputs and exchange of chemicals, and determine effects of specific military activities (i.e., sedimentation, nutrient release and discharge events) versus local and regional human and natural (climatic) drivers of water column chemistry. The monitoring program is designed to evaluate short and long-term effects of these chemical drivers on the structure, function and sustainability of the NRE in a regime of climatic variability. It will also serve as a critical source of data for supporting the project research components.

6.1.4.3.2 Relevance to the Base

The purpose of the NRE water column chemistry monitoring is to ensure sustainability of Base activities into the future and to improve management capacity for NRE. Monitoring data will provide the Base with information regarding local and regional water quality in order to address actions under the CWA [NCDWQ's nutrient-sensitive water designation, future TMDLs and CWA Section 305(b)]. The estuary's water column is the prime recipient of nutrients, organic matter and sediments originating from current and prior (historic) Base activities, including soil disturbance, wastewater discharge, PB, amphibious training, relative to local and regional agricultural, urban and industrial activities. Development on the Base and surrounding areas increases the quantity of runoff and may decrease the quality of water flowing into the estuary through the addition of nutrients, sediments and pathogens. The water column chemistry component will focus on applying measurements and indicators capable of identifying and distinguishing Base from local (i.e., nearby municipalities, agricultural operations) and regional chemical stressor sources. Another critical facet of this component will be to examine the interactive effects of climatic variability (rainfall, runoff) and change (i.e., changes in hurricane and drought frequencies and intensities), which will be critical for understanding and interpreting the delivery from and relative importance of base, local and regional chemical stressors.

6.1.4.3.3 Scale

The design of the Aquatic/Estuarine Module's water column monitoring will account for the dynamic physical-chemical inputs and processes operating within the estuary, in conjunction with the estuary's water- and airsheds, and the complex geomorphology of this ecosystem. Sampling stations are stratified throughout the estuary and paired to capture the effects of military operations. Six fixed vertical profiling and 2 AVP stations (8 sites total) will be sufficient to not only provide information about effects of military use, but to also make generalizations about regional coastal creek function as sources of nutrients, sediments, and organic matter. A primary objective of this module is to support the data needs for the research components aimed at developing and applying indicators of ecological and biogeochemical change as mediated by inputs and outputs of physical-chemical drivers. The Aquatic/Estuarine Module Team will document and couple historic and contemporary trends in the important variables with respect to causes, effects, and modulation of nutrient, contaminant and sediment stressors. The design incorporates the appropriate temporal scales capable of capturing episodic, synoptic, seasonal and inter-annual cycles and trends that affect critical processes at local and regional spatial scales for the key estuarine habitats. Frequencies and intensities of measurements along these scales are

complementary with aircraft and satellite remote sensing capabilities, enabling researchers and managers to “scale up” from point measurements to airshed, watershed and ecosystem-level assessments.

6.1.4.3.4 Linkages within the Module and among other Modules’ Monitoring Components

Because of the central role the NRE plays in MCBCL and regional ecosystem processes, this component of the Aquatic/Estuarine Module will be closely and extensively linked to all other Aquatic/Estuarine Module monitoring components (e.g., tidal creeks), as well as other modules. Watershed characterization from the Terrestrial Module will be linked by a watershed model to our tributary monitoring and modeling to provide information about the effects of land use on watershed exports of materials. Watershed sediment loading measurements will be linked to marsh accretion studies in the Coastal Wetlands Module, and the Coastal Wetlands Module’s assessments of nutrient processing at the land-water margin will be incorporated into our watershed modeling of nutrient and sediment loading. The import term for atmospheric nitrogen to the estuary by the Atmospheric Module will be critical for assessing the response of the water column to external loading. Data from the Coastal Barrier Module will supply the required information on estuarine-shelf exchanges of water and materials, as the coastal ocean can be either a source or a sink for the estuary. The linkages above are representative examples of the nearly infinite connections of the estuary’s water column to its local and regional surroundings.

6.1.4.3.5 Methods

Spatial/Site Locations

Eight stations (**Figure 6-4**), including 6 vertical profiling and 2 continuous AVP monitoring stations and a boat-mounted data-flow continuous sampler will complement existing monitoring activities by MCBCL, UNC-Wilmington, NCDWQ, and other stakeholders. The sites are distributed throughout the estuarine salinity gradient and are also in pairs of high and low impact from military operations, respectively. The sampling network will measure key inputs to and outputs from the NRE, as well as sites of intense productivity and nutrient and oxygen cycling. Stations will extend longitudinally from the long-term USGS streamgage on the New River to the inlet. The AVPs will be equipped with rain collector/gages that will be sampled during the monitoring run to obtain data on direct wet deposition to the estuary. These data will be compared with on land deposition data collected by the Atmospheric Module. An adaptive monitoring program will be developed for the purpose of (a) supporting the research component informational needs, (b) capturing event-scale (storm) impacts on the NRE, and (c) providing an opportunity for calibration of developed models and remote sensing. The estuarine monitoring program will benefit from the mapping from the subtidal to shoreline regions, including Light Detection and Ranging (LIDAR), side scan sonar, aerial photography, and satellite imagery in coordination with MCBCL.

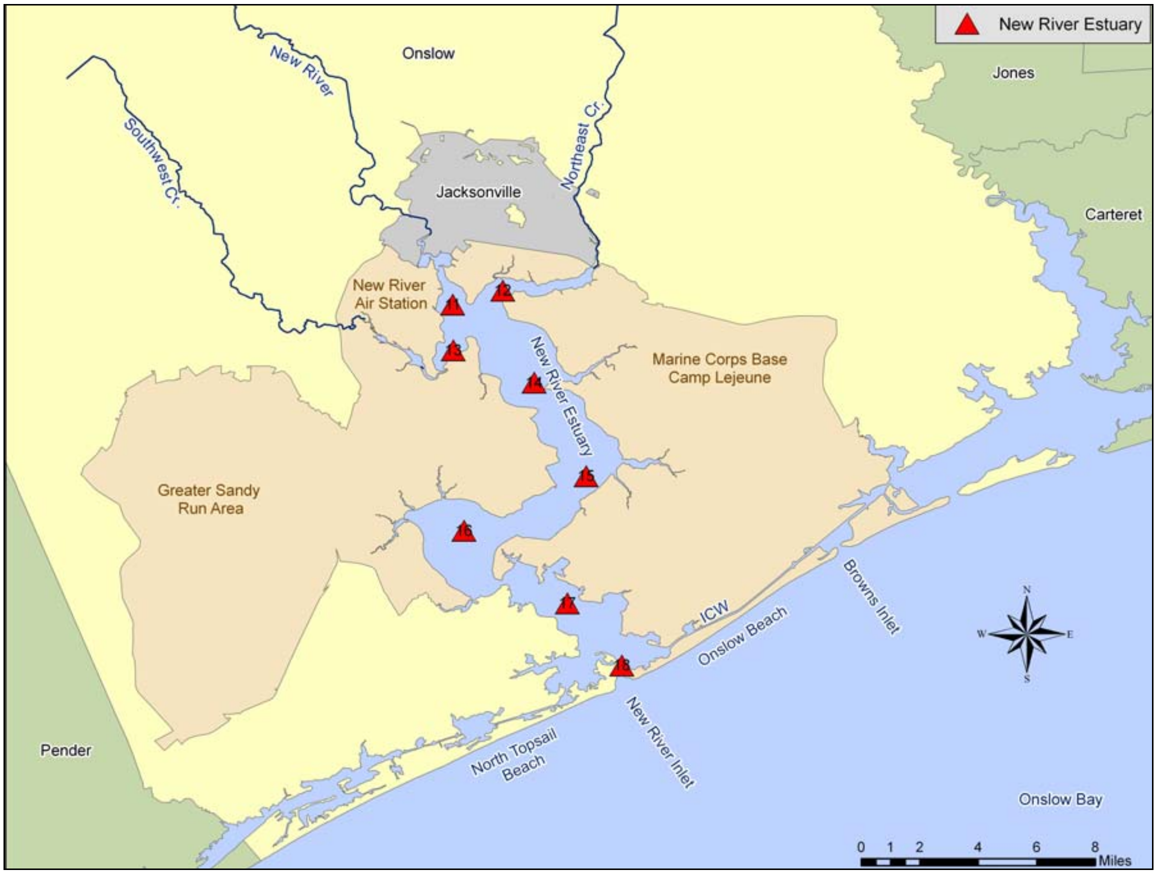


Figure 6-4. New River Estuary – water column chemistry monitoring stations.

Temporal Considerations

Based on the informational needs of the research projects described in the DCERP Research Plan and the spatial-temporal scales needed to capture key drivers and their impacts on water quality and habitat condition, appropriate sampling intervals will be chosen. It is estimated that these will be on the same order as average water residence time in the estuary (1–2 months). Sampling stations will be chosen, based on initial mapping of the system, and will be stratified based on depth. More intensive sampling will occur before and during episodic storm events. Sampling will occur year-round, but will also be focused on specific hydrologic and nutrient-contaminant-sediment loading events, which tend to be concentrated between late winter and fall months (early March – late October).

Personnel

- Senior Researcher: Hans Paerl
- Supporting Researchers: Michael Piehler and Rick Luettich
- Graduate student: (1)
- Undergraduate student: 1 Summer Undergraduate Intern
- Technicians: 1 Field Technician and 1 Laboratory Technician (nutrient chemistry)

Parameters/Variables

- Photosynthetically active radiation (PAR)
- Salinity
- Temperature

- DO
- pH
- Turbidity
- Fluorescence (Chlorophyll *a*, CDOM)
- DIN [nitrite + nitrate (NO_2^- + NO_3^-), NH_4^+]
- DIP
- DON
- Total phosphorus
- Total nitrogen
- TSS
- Particulate C and N (C,H,N)

Field and Laboratory Procedures

Sampling Design and Collection. At each station we will obtain vertical profiles of PAR, salinity, temperature, DO, pH, turbidity, and fluorescence. Precombusted GFF filters will be used to filter water samples, which will be analyzed for nitrite + nitrate (NO_2^- + NO_3^-), ammonium (NH_4^+), DIP, dissolved organic N and P using standard protocols and calibration procedures (Strickland and Parsons, 1978; Lachat Quick Chem. IV; Lachat Instruments, Milwaukee, WI, USA). Particulate organic carbon and nitrogen retained by the filters will be measured on an elemental analyzer. Samples also will be analyzed for CDOM and TSS in order to develop relations between light penetration and solids/chlorophyll *a* levels. ArcInfo and spatial statistics will be used to estimate average bathymetric areas for the 0-1 and 1-2 meter and greater than 2 meter depth intervals in order to calculate nutrient and C loads in relation to key chemical and biotic response parameters, including productivity, phytoplankton biomass and hypoxic volume.

Equipment Used.

Items marked with (*) are presently owned by the Aquatic/Estuarine Module Team.

Field:

- Two AVPs, equipped with YSI 6600 multi-probe sensors and data modules. Two backup YSI multi-probe sensors.
- YSI DataFlow continuous water quality analyzer w/multi-probe 6600 sonde and modem
- Two YSI 6600 sondes for shipboard monitoring
- Two Sea-Bird Electronics, Inc. SBE-37 Conductivity/Temperatures/Depth Profilers
- Acoustic Doppler Current Profiler (ADCP) (*)

Please Note: In tandem, these instruments allow for continuous sampling and analysis of water quality (salinity, pH, DO, turbidity, temperature, fluorescence, current velocity, depth) from a moving vessel at depths of 2 meters. This will allow us to scale up to the entire estuarine landscape.

Laboratory equipment:

- Lachat 8000 nutrient autoanalyzer (*)
- Shimadzu SPD M20A 11 High performance liquid chromatograph (*)
- Turner, Model TD 700 fluorometer (*)
- Shimadzu 5000 TOC analyzer (*)
- Shimadzu 160A Spectrophotometer (*)
- Perkin-Elmer Model 2400 C,H,N analyzer (*)

Data Management

Data downloaded from loggers will be checked by technical staff. Laboratory notes and data will be recorded daily in bound laboratory notebooks. Information entered into notebooks from machine printouts will be verified twice and the originals will be filed. Data entered from notebooks into computer files will be verified and validated. This operation will be repeated until two consecutive verification checks yield no errors. Two copies (backup and original) will be kept of all computer files at all times.

6.1.4.3.6 Data Analysis, Products, and Outcomes

Concentrations of inorganic and organic nutrients and measures of particle suspensions will be used in conjunction with water current velocity measurements to estimate flux and loading of those materials to the estuary. Loading rates will be directly applicable to the Estuarine Simulation Model (ESM) for the region for calibration and validation of loadings due to specific land-uses, atmospheric, marsh and or oceanic inputs. The suspended sediment loads will be applicable to marsh elevation model (Research Project CW-1) as they represent an important part of the source term for marsh sediment trapping.

When appropriate, data will be subjected to statistical analyses. Errors will be detected by abnormally high coefficients of variation between replicates. Experiments will be replicated, repeated, and analyzed statistically. In the event of an error, the experiment will be repeated. If high variability is still observed this will indicate a problem in materials used in the analysis or procedures followed by the personnel. Should this arise, an immediate and thorough review of materials and procedures will be conducted by the Senior Researcher and appropriate changes made.

As part of DCERP Aquatic/Estuarine baseline monitoring, environmental data will be collected on several environmental parameters, including five component indicators (chlorophyll *a*, dissolved inorganic nitrogen, dissolved inorganic phosphorus, water clarity, and DO in bottom water) included in the EPA's Water Quality Index (WQI). The WQI threshold values designated for southeast coastal estuaries (**Table 6-3**) (U.S. EPA, 2004a). After the first year of monitoring, a WQI will be calculated for each of the NRE stations to use as a benchmark value for assessing changes in water quality in the estuary over the next 10 years. At the end of each year of monitoring, a map of the estuary will be compiled showing the WQI values attained at each of the individual monitoring stations. These will be developed using the stoplight color approach (red, yellow and green) employed by the U.S. EPA in their National Coastal Condition Reports (U.S. EPA, 2001; 2004a) as well as in the National Estuary Program Coastal Condition Report (U.S. EPA, 2006a). This map will provide a quick at a glance view of the water quality conditions in the NRE and how they change over time. This map will provide resource managers with an easy to read map water quality conditions that do not meet the EPA threshold standards. The EPA approach will be compared to the chlorophyll *a* indicator approach proposed in the Research Project AE-1. Although the proposed chlorophyll *a* indicator used by the State of North Carolina is currently > 40 μg/L, the State may consider using a more stringent chlorophyll *a* value in succeeding years to evaluate eutrophication in their coastal estuaries.

Table 6-3. EPA Water Quality Index Components

EPA Water Quality Index (WQI) Components	Good	Fair	Poor
Chlorophyll *a*	< 5 μg/L	5–20 μg/L	> 20 μg/L
DIN	< 0.1 mg/L	0.1–0.5 mg/L	> 0.5 mg/L
DIP	< 0.01 mg/L	0.01–0.05 mg/L	> 0.05 mg/L
Water Clarity Index (WCI)[a]	WCI ratio is > 2	WCI ratio is between 1 and 2	WCI ratio is < 1
DO	> 5 mg/L	2–5 mg/L	< 2 mg/L

[a] WCI = (observed clarity at 1 meter water depth)/(regional reference clarity at 1 meter water depth)

6.1.4.4 New River Estuary - Water Column Primary Producers

6.1.4.4.1 Objective(s)

Module team members will quantify and characterize (as to microalgal communities and their environmental controls) water column primary production in the NRE. A bulk of the estuary's primary production is derived from the suspended microalgae or phytoplankton (Mallin et al., 2005). In order to quantify and understand the critical role phytoplankton play in supporting the estuary's food web, cycling of nutrients and oxygen, water quality and habitat condition, phytoplankton community productivity, biomass, and composition must be determined. In addition, understanding and modeling the fate of water column productivity with respect to higher trophic levels, including zooplankton, finfish and shellfish, as well as benthic infauna, flora, nutrient cycling and habitat condition (i.e., hypoxia) are essential, integral informational products provided by a water column monitoring program. Sampling locations will be stratified to assess variability in productivity and environmental controls within and among the estuarine salinity zones.

6.1.4.4.2 Relevance to the Base

The purpose of this module is to ensure sustainability of Base activities into the future and to improve management capacity for NRE. Data will provide information pertinent to meeting the water quality criteria and to avoid actions under the CWA Section 305(b), including TMDLs. Water column primary production supports the NRE's food web, mediates nutrient and oxygen cycling, and is a key determinant of estuarine water quality and habitat condition. Nutrient, sediment and contaminant discharge associated with land use (changes), and hydrologic modifications arising from base, as well as local and regional activities, modulate primary production, as well as biomass and composition of phytoplankton mediating this important process. The NRE has a history of potentially HABs that has been attributed to human- and climatically induced changes in physical-chemical environment, including changes in the above-mentioned drivers. We will apply well-established and novel, readily deployable and quantifiable indicators of primary production, phytoplankton biomass and composition to determine the status and trends of primary production at key estuarine locations under the influence of nutrient, sediment and contaminant discharge, as well as hydrologic modifications. These will reflect Base activities, including soil disturbance, wastewater discharge, PB, amphibious training, as well as local and regional agricultural, urban and industrial activities. This component will also examine the interactive effects of climatic variability (e.g., rainfall, runoff) and change (i.e., changes in hurricane and drought frequencies and intensities), which impact this region.

6.1.4.4.3 Scale

The design of the Aquatic/Estuarine Module's primary production monitoring will account for the dynamic interplay of nutrient, sediment and other contaminant inputs, physical alteration (i.e., changes in turbidity, circulation, flow and water residence time), and geomorphology of the system. Data obtained by this module will support the research components aimed at developing and applying indicators of ecological and biogeochemical change as mediated by inputs and outputs of physical-chemical drivers. This module will document and couple historic and contemporary trends in the important variables and will support research aimed at clarifying the causes, effects, and modulation of phytoplankton community changes, including the development and persistence of HABs, and their linkages to perturbations of ecological and management concern (e.g., toxicity, hypoxia). The design will incorporate the appropriate temporal scales capable of capturing episodic, synoptic, seasonal and inter-annual cycles and events that affect rates, composition and fate of primary producers. Frequencies and intensities of measurements along these scales will allow for coupling to remote sensing and support modeling to "scale up" from point measurements to ecosystem-level assessments.

6.1.4.4.4 Linkages within the Module and among other Modules' Monitoring Components

Because of the central role NRE primary production plays in supporting MCBCL and regional ecosystem processes and services, the Aquatic/Estuarine Modules' primary productivity monitoring will be closely and extensively linked to all other modules. When coupled to the water column and sediment nutrient cycling component, this facet of the monitoring program will link terrestrial, atmospheric, wetland and coastal nutrient, sediment and contaminant inputs, as well as hydrologic modifications to a set of indicators of estuarine water quality and trophic state. This module will support modeling aimed at linking land use, watershed inputs (Terrestrial Module), and the effects of marsh accretion/loss studies in the Coastal Wetlands Module, as well as the Coastal Wetlands Module's assessments of nutrient processing at the land-water margin. Similarly, the role of direct and indirect atmospheric nitrogen supply to the estuary as measured by the Atmospheric Module will be critical for assessing the response of the water column to external loading. Data from the Coastal Barrier Module will supply the required information on estuarine-shelf exchanges of water and materials mediating primary production in the estuary. We will utilize monitoring data collected from shared locations along the estuary and its margins to support research aimed at establishing, modeling and remotely sensing (to scale up) these links.

6.1.4.4.5 Methods

Spatial/Site Locations

We plan on 6 ship-based vertical profiling and 2 continuous AVP monitoring stations and a boat-mounted data-flow continuous sampler that will complement existing monitoring activities by MCBCL, UNC-W, and NCDWQ (**Figure 6-5**). The sampling network is designed to (1) link key sites of nutrient, sediment, contaminant inputs and outputs from the NRE to primary production and phytoplankton biomass and compositional responses. Stations extend longitudinally from the long-term USGS streamgage on the New River to the inlet. The sampling network include sites on freshwater and brackish tributaries draining to the NRE. This adaptive monitoring program has been developed for the purpose of a) supporting the research component informational needs, b) capturing event scale (storm) impacts on production dynamics in the NRE, and c) providing an opportunity for calibration of developed models and remote sensing. The Aquatic/Estuarine Module's primary production monitoring will benefit from aerial photography, satellite and aircraft remote sensing imagery (SeaWiFS, MODIS, MERIS), coordinated with MCBCL.

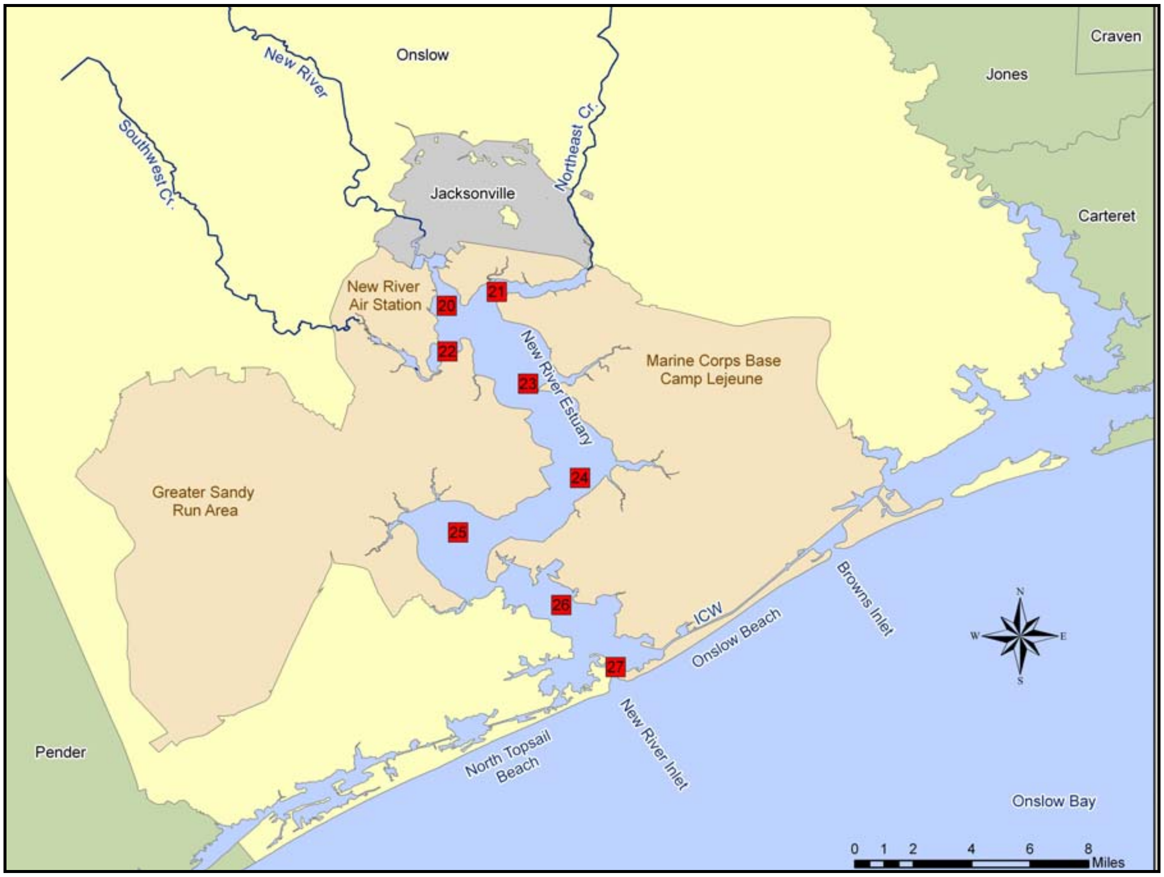


Figure 6-5. New River Estuary - water column primary production monitoring stations.

Temporal Considerations

Based on the informational needs of the research projects and the spatial-temporal scales needed to capture key drivers and their impacts on water quality and habitat condition, appropriate sampling intervals will be chosen. It is estimated that these will be on the same order as average water residence time in the estuary (1–2 months). Sampling stations will be chosen, based on initial mapping of the system, and will be stratified based on depth. More intensive sampling will occur before and during episodic storm events. Sampling will occur year-round, but will be focused on the period of maximum primary production and HAB potential, which runs from late February through October.

Personnel

- Senior Researcher: Hans Paerl
- Supporting Researchers: Michael Piehler and Rick Luettich
- Graduate student: 1 Graduate Research Assistant
- Undergraduate students: 1 Summer Undergraduate Intern
- Technicians: 1 Field Technician and 1 Laboratory Technician

Parameters/Variables

- Fluorescence (Chlorophyll *a*, CDOM)
- Primary productivity measurements (*in situ* ^{14}C method)
- Diagnostic photopigments (these will be measured in conjunction with the phytoplankton research module)

- Microscopic analyses of phytoplankton community composition
- TSS

Field and Laboratory Procedures

Sampling Design and Collection. At each AVP station, samples will be analyzed for CDOM and TSS in order to develop relations between light penetration and solids and chlorophyll a levels. Samples from profile and flow-through sampling locations will be filtered (GFF filters) for chlorophyll a analysis, which will be done fluorimetrically on 90% acetone extracted samples. A replicated set of filters will also be extracted for HPLC analysis of diagnostic (for different algal groups) phytoplankton groups (Research Project AE-1). In addition, data on ^{14}C-determined PP measurements will be integrated with Research Project AE-1. ArcInfo and spatial statistics will be used to estimate average bathymetric areas for the 0–1 and 1–2 m and > 2m depth intervals in order to calculate aerial phytoplankton biomass and primary production.

Equipment Used.

Items marked with (*) are presently owned by the Aquatic/Estuarine Module Team.

Field:

- Two AVPs, equipped with YSI 6600 multi-probe sensors and data modules.
- YSI DataFlow continuous water quality analyzer w/multi-probe 6600 sonde and modem
- Two YSI 6600 sondes for shipboard monitoring
- ACDP(*)

Please Note: These instruments allow for continuous sampling and analysis of water quality (salinity, pH, DO, turbidity, temperature, fluorescence, current velocity, depth) from a moving vessel at depths of 2 m. This will allow us to scale up to the entire estuarine landscape.

Laboratory Equipment:

- Shimadzu SPD M20A 11 High performance liquid chromatograph (*)
- Turner, Model TD 700 fluorometer (*)
- Shimadzu 160A Spectrophotometer (*)
- Beckman 6500 Liquid scintillation counter (*)

Data Management

Data downloaded from loggers will be checked by technical staff. Laboratory notes and data will be recorded daily in bound laboratory notebooks. Information entered into notebooks from machine printouts will be verified twice and the originals will be filed. Data entered from notebooks into computer files will be verified and validated. This operation will be repeated until two consecutive verification checks yield no errors. Two copies (backup and original) will be kept of all computer files at all times.

6.1.4.4.6 Data Analysis, Products, and Outcomes

Results will be used and applied in diverse ways, across multiple modules. Data will be GIS referenced and analyzed to map primary production, phytoplankton biomass, HABs and examine the space-time relationships between nutrient, sediment and other contaminant inputs, phytoplankton production responses under variable hydrologic conditions. The chlorophyll *a* and associated data will also be input to the ecosystem nutrient-phytoplankton-hypoxia response model being developed in Research Project AE-2 and the probabilistic Bayesian Belief model being developed in Research Project AE-1. Phytoplankton data will be formatted so as to be of direct use (along with turbidity and CDOM) to serve

as a calibration and verification source for remote sensing efforts aimed at scaling up production and HAB dynamics to the entire estuary. Lastly, chlorophyll *a* and associated physical-chemical data will serve as “standard” for TMDLs, nutrient sensitive water designations and CWA Section 305(b) criteria of water quality and habitat conditions.

When appropriate, data will be subjected to statistical analyses. Errors will be detected by abnormally high coefficients of variation between replicates. Monitoring analyses will be replicated, repeated, and analyzed statistically. In the event of an error, the analysis will be repeated. If high variability is still observed this will indicate a problem in materials used in the analysis or procedures followed by the personnel. Should this arise, an immediate and thorough review of materials and procedures will be conducted by the Senior Researcher and appropriate changes made. An indicator for chlorophyll *a* will be used to identify sites with healthy, transitional, and poor condition with respect to chlorophyll *a* concentrations in water samples (**Table 6-4**). The indicator and associated thresholds will be used to identify areas of the NRE with chlorophyll *a* acceptable criteria.

Table 6-4. Proposed Chlorophyll *a* Indicator

Indicators	Condition			Comment/Source for the indicator and threshold values
	Healthy	Transitional	Poor	
Chlorophyll *a*	< 20 μg/L	20–40 μg/L	> 40 μg/L	Threshold developed as part of the NCDENR Chl *a* “acceptable” water quality criteria (NCDENR, 1999). The monitoring design will be flexible in order to evaluate revised criteria.

6.2 Coastal Wetlands Module

6.2.1 Introduction

Coastal wetlands are a vital component of the estuarine landscape that link terrestrial and freshwater habitats with the sea (Levin et al., 2001). Marshes improve water quality by acting as nutrient transformers and trapping sediment; attenuate wind wave, and boat wake energy; provide critical habitat area for a diverse group of estuarine organisms; serve as nursery habitat for commercially important fishery species; help stabilize the coastal barriers; accrete sediments and build land; and provide recreational opportunities for people (Jordan et al., 1983; Knutson, 1988; Valiela and Teal, 1979; Morris, 1991; Kneib, 1997; Moller et al., 1999). The coastal wetlands of this module are defined as the vegetated and non-vegetated intertidal habitat in salt and brackish waters, and include marshes and adjacent mudflats, sandflats, and tidal creeks. Marshes within the MCBCL region are typically dominated by smooth cordgrass *(Spartina alterniflora*) and black needle rush (*Juncus roemerianus)*. Although these marshes represent less than half of the designated wetlands on MCBCL, they are the only wetland areas that directly adjoin (or sometimes intersect) amphibious military training exercises, and are also the only wetlands that play a role in barrier island stabilization. **Figure 6-6** presents the conceptual model for the Coastal Wetlands Module. The crucial aspects of coastal wetlands that will be monitored include (1) delineation of historic and present marsh distribution and composition using remote sensing and ground-truthing,:(2) determination of present-day marsh surface elevation, accretion rates, and hydroperiod; and 3) measurement of flow rates and nutrient chemistry of shallow ground water entering the estuary via coastal wetlands. These data will provide baseline information for the research projects, both within the Coastal Wetlands Module and for research projects in the Aquatic/Estuarine and Coastal Barrier modules.

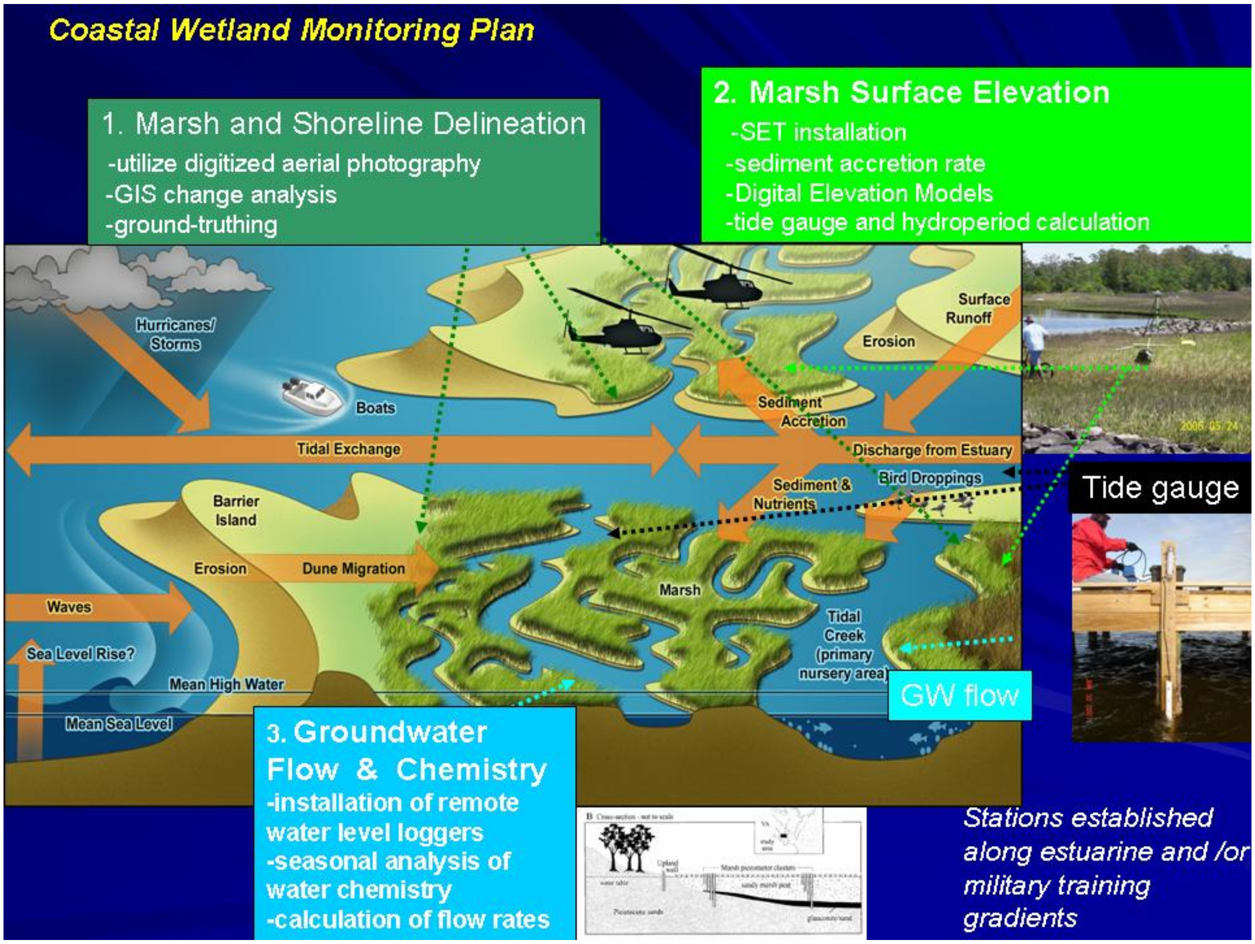


Figure 6-6. Conceptual model for the Coastal Wetlands Module.

6.2.2 Coastal Wetlands Module Objectives and Activities

The Coastal Wetlands Module monitoring program is focused on providing baseline data to determine the ability of marshes within the NRE to provide a variety of ecosystem services and, in combination with research projects, to determine what factors affect marsh structure and function (**Table 6-5**). The overall goal is to develop a management plan that supports the sustainability of marsh ecosystems and the estuarine shoreline. Coastal wetlands provide a variety of ecosystem services that are addressed by the Coastal Wetlands Module's monitoring and research, such as (1) improving water quality by acting as nutrient transformers and trapping sediment (Harrison and Bloom 1977, Valiela and Teal 1979, Jordan et al., 1983), (2) stabilizing estuarine shorelines via attenuation of wind wave and boat wake energy (Knutson, 1988; Moller et al., 1999; Leonard et al., 2002), (3) providing critical habitat area for a diverse group of estuarine organisms and serving as nursery habitat for commercially important fishery species (Kneib, 1997), and (4) stabilizing coastal barrier islands via sediment accretion (Roman et al., 1997). The rate and magnitude at which these ecological processes occur is dependent upon a combination of biological characteristics of the marsh and physical and chemical characteristics of the environment. The monitoring plan for the Coastal Wetlands Module will obtain baseline rates and measures of these processes, assess temporal and spatial variability, and determine how stresses imposed as a consequence of MCBCL and other direct anthropogenic activities may alter the provision of these ecosystem services. Foremost, the monitoring plan provides information needed to manage MCBCL coastal wetlands.

Table 6-5. Coastal Wetlands Module Monitoring Components

Component	Variable(s)	Spatial Scale	Temporal Scale
Land cover and Shoreline Erosion	Wetland habitat distribution and composition	Entire NRE	Photos and Imagery from 1938 to present
	Marsh composition and abundance by species, density, and mean stem height	18 stations	Annually
	Shoreline location and elevation	Entire NRE; 9 stations in detail	Biennially and event based
Marsh Surface Elevation	Marsh surface elevation (sediment accretion)	18 stations	Spring and fall
	Water level, temperature, salinity (for hydroperiod calculations)	2 stations	Continuous 6-minute intervals
	Sediment (percent organic content, particle size)	18 stations	Biennially
	Digital Elevation Models (DEMs) - surface elevation	18 stations	Annual
Nutrient chemistry	Ammonia (NH_3^+), nitrate (NO_3^-), salinity, sulfate (SO_4^{-2}), DON, SRP, ferrous, hydrogen sulfide, DOC, hydraulic gradient, hydraulic conductivity	3 stations	Chemistry - Seasonal; Hydrology-Continuous

Table 6-6 summarizes the estimated level of effort for each of the key personnel during the first four years of Phase II for the monitoring activities previously listed in **Table 6-5**. A specific list of the personnel for each monitoring activity is located within the Methods section of each monitoring activity described in Section 6.2.4 (*Coastal Wetlands Module Monitoring Components*).

Table 6-6. Coastal Wetlands Module's Estimated Staffing of Monitoring Activities

	Time in months/year			
Personnel	**Year 1**	**Year 2**	**Year 3**	**Year 4**
Jim Morris	1	1	1	1
Carolyn Currin	2	2	2	2
Mark Fonseca	1	1	1	1
Craig Tobias	1	1	1	1
Technicians (2)	12	12	12	12
Modeler (1)	3	3	3	3

6.2.3 Benefit to MCBCL

The monitoring component will provide information that will directly help MCBCL meet one of its key military drivers: to preserve the integrity of the amphibious maneuver areas in the NRE. The distribution and species composition of coastal wetlands and the rate at which these wetlands are either accreting sediments or eroding are key parameters in understanding whether the back-barrier-estuarine shorelines are sustainable under current environmental conditions and military training programs, and to help predict how changes in sea level, storm events, and/or changes in military training activities may affect the sustainability of the estuarine shoreline. Ultimately, the baseline data collected in this module will help MCBCL adopt a proactive approach for land use along the shoreline and minimize adverse impacts of military training to coastal wetlands and shoreline habitats.

Accurate tide level data and shoreline erosion rates will also support MCBCL to maintain or improve water quality in the NRE. Biogeochemical processes in the intertidal zone, including nutrient cycling and primary production, as well as groundwater fluxes and sedimentation rates, are controlled to a significant degree by hydroperiod. The tide gauge data collected in this monitoring effort will support accurate calculations of hydroperiod and will help improve planning of military operations that are tide-dependent.

6.2.4 Coastal Wetlands Module Monitoring Components

6.2.4.1 Landcover and Shoreline Erosion

6.2.4.1.1 Objective(s)

Threats to coastal wetlands include erosion from wind and boat waves; erosion from intense coastal storms, dredging, trampling, subsidence due to compaction or fluid extraction; and sea level rise. Invasive and/or nuisance species are a growing issue for management of coastal wetlands, particularly in areas subject to development and disturbance. Monitoring of shoreline and marsh land cover will provide the baseline information required to detect changes due to wave erosion, storm events, and invasive species. It will also provide the information required to support research projects designed to develop effective shoreline stabilization plans and to inform Base management of wetland invasive species (specifically *Phragmites australis*). The spatial and temporal extent of the monitoring activity will also help determine whether impacts from military activities (e.g., Landing Craft Air Cushion [LCAC] exercises, splash points) have a significant impact on marsh shoreline erosion above that from storm events, recreational boat traffic, and/or sea level rise.

6.2.4.1.2 Relevance to the Base

Military activities at MCBCL have both direct and indirect impacts on coastal wetlands, and this module addresses MCBCL military drivers: to preserve the integrity of the amphibious maneuver areas in the NRE. Direct effects of military activities may result from LCAC operations, splash points along the estuarine shoreline, military boat traffic, dredging and/or marina construction, vehicles traversing barrier islands, and the potential of tracked vehicles operating over marshes. Indirect effects may result from runoff from impact areas and land application of residuals from wastewater treatment plants.

Estuarine shoreline erosion is an important issue to the Base, both as it affects its ability to conduct military training and as it affects shoreline infrastructure (e.g., housing, offices). Alternative shoreline stabilization structures and wetland restoration activities have been considered by MCBCL in the past, and results of Coastal Wetlands Module monitoring activities, in conjunction with research results, will provide information to support effective management decisions.

Coastal Wetlands Module monitoring will also provide baseline data to track the spread of the invasive strain of *Phragmites australis*, a marsh macrophyte that can significantly alter the structure and function of coastal marshes. The spread of *Phragmites* has been linked to disturbance, and millions of dollars have been spent on control and remediation efforts. Although at this time *Phragmites* control is not a significant issue for the Base, it is likely to become one in the future. *Phragmites* is currently frequently found along the ICW in both disturbed areas and at the upper marsh fringe. Although DCERP does not currently have any targeted research addressing *Phragmites*, the data collected would support such an effort in the future by conducting an inventory of *Phragmites* at the selected marsh sites.

6.2.4.1.3 Scale

This monitoring activity would be conducted across different spatial and temporal scales, depending on the parameters and methodology involved.

- Delineation of coastal wetland distribution and shoreline edge throughout the installation using high resolution remote sensing (3 m to .33m horizontal resolution) of wetland and shoreline

habitats is available via efforts conducted by MCBCL and the State of North Carolina. These include LIDAR data (NC Flood program, 2002) with a vertical resolution of 15 cm, multispectral IKONOS imagery (2006), and color and infrared aerial photography (2004). Additional imagery will be used as available.

- Annual monitoring of fixed transects would be done on a 1-m2 plot scale, but plots would be distributed along an installation-wide gradient to represent different physical settings, different levels of military activity, and to capture items of management interest (e.g., *Phragmites* distribution, LCAC routes; see **Figure 6-7**). Mapping would include a delineation of marsh boundaries using Mapping Grade Trimble ProXr units. These maps would be made available in GIS format.

6.2.4.1.4 Linkages within the Module and among other Modules' Monitoring Components

All monitoring activities within the Coastal Wetlands Module have been coordinated with the Coastal Wetlands Module research projects. In addition, the Aquatic/Estuarine Module will monitor at Sites 5, 7, and 8 sample one of our Shoreline sites (A); see **Figure 6-7**. This paring of sites with the Aquatic/Estuarine Module will allow us to examine the relationship between marsh processes and the structure and function of adjacent subtidal communities. We will coordinate sampling the marsh behind the barrier island at Sites 7 and 8 with the Coastal Barrier Module monitoring activities. Changes in marsh vegetation and shoreline erosion may have significant effects on variables measured by the Aquatic/Estuarine and Coastal Barrier modules, and by sharing sites we will be able to assess these linkages.

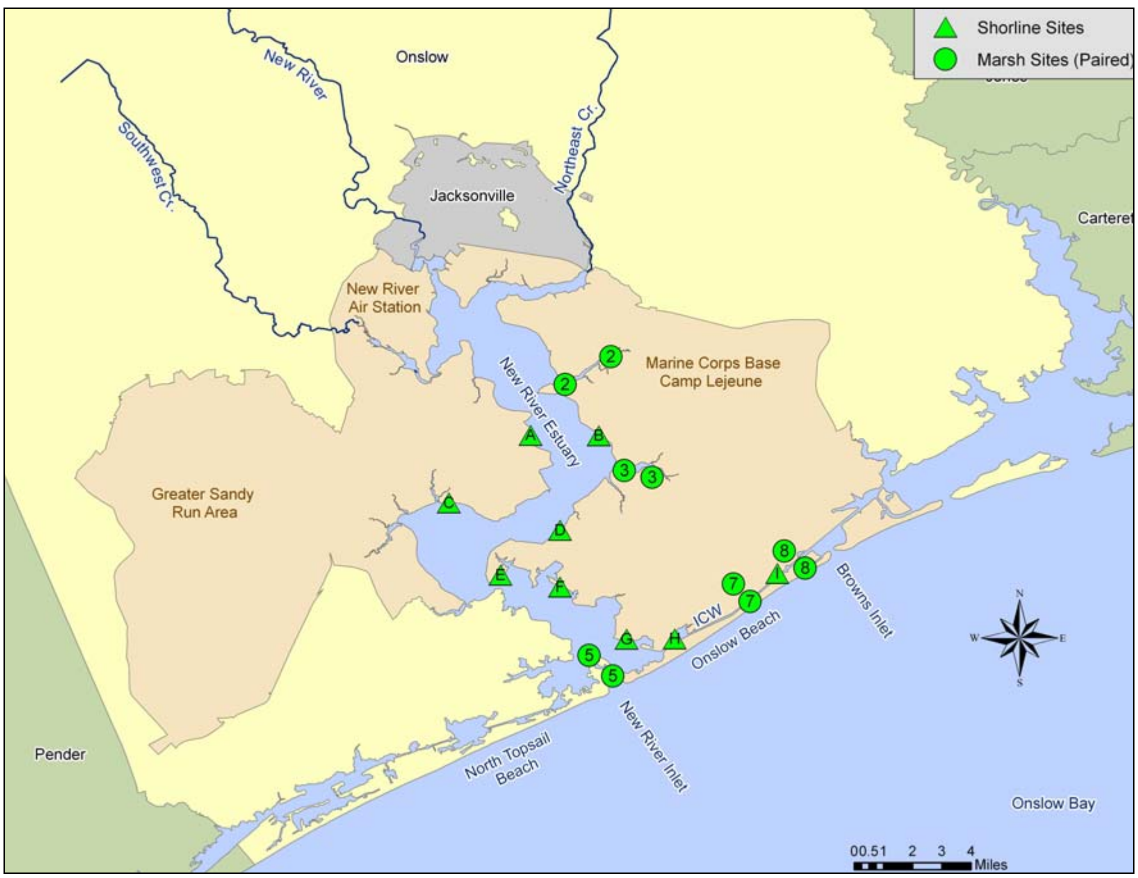


Figure 6-7. Map of proposed monitoring stations for Coastal Wetlands Module.

6.2.4.1.5 Methods

Spatial/Site Locations

Figure 6-7 illustrates the proposed sites for the monitoring activities associated with the Coastal Wetlands Module. At the marsh sites, the following monitoring activities will occur: land cover, marsh species composition and density, surface elevation table (SET), DEM, and nutrient chemistry. There will be a pair of stations at each proposed sampling location: Wallace Creek (Site 2), French Creek (Site 3), TMZ Bluebird (Site 5), Gilletts Creek (Site 7), and Freeman's Creek (Site 8). At the Shoreline sites, the following activities will occur: land cover, stabilization studies, SET, and DEM.

Sampling site locations were selected to include the range of physical and geomorphological characteristics within MCBCL, which support coastal wetlands, reflect a range of military activities and potential impact, and include areas of special concern to MCBCL. Marsh sites were selected at 5 locations to evaluate military impacts (runoff zones from military impact zones, as well as physical disturbance zones [splash points and LCAC]) on coastal wetlands in a range of environments. Sites were also selected in consideration of anticipated monitoring by other modules; it is anticipated that the majority of Coastal Wetlands Module monitoring stations will also be sampled by other modules for different parameters. Specifically, Aquatic/Estuarine Module research and monitoring of sediment characteristics and benthic-pelagic coupling will occur at the Coastal Wetlands sites designated 3, 5, 7 and 8. Coastal Barrier Module research on overwash and sediment processes will include back-barrier island locations at sites 7 and 8.

Shoreline erosion sites A-I were selected based on the following (1) areas identified as concerns for shoreline erosion (USACE, 2001); (2) gradient in wave energy and vessel traffic; and (3) outside of "no-go" zones (see map in **Appendix D**).

Marsh sites will be sampled in pairs to provide information on small-scale and large-scale variability, and to provide finer measures of stressors on marsh structure and function. The sites include the following:

- Site 2 (Wallace Creek): Low military use, lower salinity and wave exposure setting
- Site 3 (French Creek): Moderate military use (runoff from G-10, splash points at mouth), lower salinity and wave exposure setting
- Site 5 (TMZ Bluebird): High military use (LCAC) at one of paired stations; low at the other. This site has closest proximity to New River Inlet.
- Site 7 (Gillets Creek): Low military use, higher salinity, proximity to barrier island. Stations established on either side of the ICW.
- Site 8 (Freeman Creek): Moderate military use (G-10 impact zone runoff), higher salinity, proximity to barrier island. Stations established on either side of ICW

Temporal Considerations

- Historic and every 3 years or post-storm event high resolution remote sensing of wetland habitat distribution and composition (subject to availability of imagery/data)
- Annual monitoring of wetland plant species composition
- Twice-yearly measures of sediment accretion from SETs
- Water level data collected every 6 minutes in accordance with National Oceanic and Atmospheric Administration (NOAA) Tide Gauge operations.

Personnel

- Senior Researcher: Carolyn Currin
- Supporting Researchers: Mark Fonseca, Jim Morris, and Craig Tobias
- GIS/GPS Modeling specialist: Amit Malhotra

- Technicians: (3)

Parameters/Variables

- Wetland habitat distribution and composition (GIS data layers) using high resolution remote sensing (1/3 m resolution) and ground-truthed
- Marsh composition and abundance during peak biomass periods by species; stems m^{-2}, mean stem height
- Shoreline location (meter resolution) and elevation (2-cm resolution) (GIS data layers)

Field and Laboratory Procedures

Sampling Design and Collection.

- Landcover and shoreline habitats. Aerial photography, satellite imagery and LIDAR data from wetland areas will be utilized to prepare maps (GIS layers) of the distribution and elevation of coastal wetlands. Ground-truthing will be conducted to verify results at all sites, which will be used in other monitoring sections and in Coastal Wetlands research modules (Finkbeiner et al., 2001; Morris et al., 2005). Stratified random sampling techniques will be used to obtain data on the distribution of coastal wetland species in areas to be ground-truthed for remote sensing products, and at selected marsh and shoreline sites (**Figure 6-7**) (Elzinga et al., 1998; Morris and Haskin, 1990; Morris et al., 2005). Data on plant species, percent cover and stem density will be collected for each species encountered in 1-m^2 plots. A GPS coordinate will be obtained for each plot sampled.
- Change Analysis. GIS Spatial Analyst tools will be used to detect changes in coastal wetland distribution and species composition, and in location of shoreline edge and habitats. Change analysis will be done using protocol described in Dobson et al. (1995). Note: a previous effort was made by the U.S. Army Corps of Engineers (USACE) to utilize historic aerial photography to measure historic shoreline erosion, but that effort was marginally successful (USACE, 2001). Improvements in GIS and remote-sensing technology, in addition to our ground-truthing, may allow us to make a better hindcast of shoreline erosion, and the installation of benchmarks and DEMs (at a scale of 100s of meters to a 2-cm level of accuracy) will support efforts to track shoreline erosion in the future.

Equipment Used.

Items marked with (*) are presently owned by the Coastal Wetlands Module Team.

- Trimble 5800 Real Time Kinematic survey system (*)
- Multiple Trimble Pro XR DGPS (mapping grade) (*)
- RBR 2050 pressure sensors (wave gauges) (*)
- Laser level Survey grade (*)
- Tablet PC (*)
- ARCGIS version 9.1 & 9.4 (*)
- Boats, vehicles for access to estuarine sites (*)

Data Management

Raw and processed data will be integrated into the DCERP data and information management system. Laboratory notes and data will be recorded daily in bound laboratory notebooks. Information entered into notebooks from machine printouts will be verified twice and the originals will be filed. Data entered from notebooks into computer files will be verified and validated. This operation will be repeated until two consecutive verification checks yield no errors. Two copies (backup and original) will be kept of all computer files at all times.

6.2.4.1.6 Data Analysis, Products, and Outcomes

When appropriate, data will be subjected to statistical analyses (Sokal and Rohlf, 1981). Errors will be detected by abnormally high coefficients of variation between replicates. Experiments will be replicated and analyzed statistically. If high variability is observed this may indicate a problem in materials used in the analyses or procedures followed by the personnel. Should this arise, an immediate and thorough review of materials and procedures will be conducted by the Senior Researcher and appropriate changes made.

Distribution of coastal wetlands along salinity, wave exposure and elevation gradients will be determined and will provide input to ecosystem models, and provide information on how changes in environmental variables, sea level rise, or disturbance may alter distribution of coastal wetlands. Products will include maps and GIS layers of marsh distribution and species composition, elevations, shoreline delineation and wave energy.

6.2.4.2 Marsh Surface Elevation

6.2.4.2.1 Objective(s)

The ability of salt marshes to accrete sediments and keep up with sea level rise is a crucial component of a sustainable estuarine ecosystem. However, the rate at which marshes trap sediment and maintain surface elevation depends upon sediment availability, the rate of sea level rise, the density of marsh vegetation, belowground root production, storm intensity and frequency, and nutrient enrichment (Morris, 1991; Cahoon, 1999; Cahoon et al., 2002). Some of these controlling factors may change over long time scales, and some over very short timescales. Many of these factors can be expect to vary significantly within the MCBCJ, over both temporal and spatial scales. Military activities may directly and indirectly alter marsh surface elevations. In order to successfully manage coastal wetlands to preserve the ecosystem services they provide, it is crucial to know how the surface elevation of coastal wetlands is changing, how that response varies spatially within the range of geomorphological and physical settings within the MCBCL, what factors control the response of the marsh surface elevation, and whether military activities alter that response.

6.2.4.2.2 Relevance to the Base

Military activities at MCBCL have both direct and indirect impacts on coastal wetland surface elevations. Direct effects may result from LCAC operations, splash points along the estuarine shoreline, military boat traffic, dredging and/or marina construction, vehicles traversing barrier islands, and the potential of tracked vehicles operating over marshes. Indirect effects may result from runoff from impact areas and land-application of residuals from wastewater treatment plants.

- Can marshes be managed to increase sedimentation? Can dredge spoil be used to build marshes?
- Can we build a better bulkhead e.g., living bulkheads?
- What is the upper limit on sedimentation rates (at what rate will SLR overtake marshes)?
- Are dunes migrating over marshes? How fast?
- Are there opportunities for creating constructed marshes?
- How resilient are marshes to hurricane/storm impacts?

6.2.4.2.3 Scale

High resolution measurements (mm) will be obtained with SETs, which provide measures of surface elevation change within 1-m^2 plot. These plots will be replicated within each of the paired stations at each marsh site and at a subset of the Shoreline sites (**Figure 6-7**), to provide data at a watershed and installation-level scale. These measures can be compared at a regional scale as the two Senior Researchers have already established SETs in coastal wetlands in North Carolina and South Carolina. These high-

resolution (mm) measures are required to monitor elevation changes that may show gradual change within the lifetime of a monitoring program (years), but may have profound consequences over decades to centuries-the appropriate period for securing habitats at MCBCL. In addition, gradual changes (mm-cm) in surface elevation can alter marsh community composition, porewater chemistry and hydroperiod, all of which may alter rates of biogeochemical processes and fluxes.

DEMs will be obtained at a vertical resolution of 2-4 cm over a 500-m^2 area, at each of the Shoreline sites (A-I), and at each of the marsh sites (**Figure 6-7**). This will allow us to extend our results from SETs over much larger area, and the range of sites along a salinity and wave exposure gradient will allow us to discriminate between processes significant at a site level to those across the installation and watershed level. As with SETs, similar data acquired by the Senior Researchers in other sites in the Southeast will allow us to extend these results to a Regional level.

Water level, temperature and salinity at 2 locations within the NRE would be determined every 6 minutes, in accordance with NOAA Center for Operational Oceanographic Products and Services (COOPS) standards. Tide gauges would be installed on fixed docks or pilings (exact location to be determined) at two locations; one in the high salinity waters within or adjacent to the ICW and one in the lower salinity waters of the NRE, upstream of the bridge at Highway 172. Data will be downloaded and made available to other researchers and MCBCL staff on a quarterly basis. Installation will be done in accordance with guidelines established by NOAA

6.2.4.2.4 Linkages within the Module and among other Modules' Monitoring Components

All monitoring activities in the surface elevation monitoring will be done at sites utilized for other Coastal Wetlands Module monitoring activities. These include Marsh Sites 2, 3, 5, 7, and 8 and Shoreline Sties A-I; see **Figure 6-7**. In addition, the Aquatic/Estuarine Module will monitor at Sites 5, 7, and 8. The Aquatic/Estuarine Module will also sample one of our Shoreline sites (A). This duplication of sites with the Aquatic/Estuarine Module will allow us to examine the relationship between processes affecting marsh surface elevation and the structure and function of adjacent subtidal communities. We will coordinate sampling the marsh behind the barrier island at Sites 7 and 8 with the Coastal Barrier Module monitoring activities. Changes in marsh surface elevation may have significant effects on variables measured by the Aquatic/Estuarine and Coastal Barrier modules, and by sharing sites we will be able to assess these linkages.

Water level is a crucial parameter for modeling estuarine ecosystem response to long-term (sea-level rise) events, and for interpreting response to short-term events (hurricanes, northeasters). There are currently no tide gauges within the NRE, and our data will be provided to all other modules and to MCBCL personnel.

6.2.4.2.5 Methods

Spatial/Site Locations

See **Figure 6-7** for location of Coastal Wetlands Module sampling sites. See Section 6.2.4.1.5 for a description of how these sites vary in terms of military use.

Marsh Sites 2, 3, 5, 7 and 8. Duplicate SETs will be established at each paired station within each site, except for sites selected for nutrient addition experiments (Research Project CW-1), where three SETs per site will be established. DEMs will be obtained for each station at each site. Aboveground marsh PP will be measured annually at each station within a site

Shoreline Sites A-I. SETs will be established at a subset (at least 5) of these stations; the amount of vegetation and type of shoreline stabilization structure will determine the selection of sites. DEMs will be obtained for each shoreline site.

Temporal Considerations

- SET measures will be obtained biannually, in spring and fall. Additional measures may be taken to capture effects of storm events.
- DEMs will be obtained annually, or after significant storm events or military activities.
- Sediment characteristics (% organic matter, article-size) will be determined at each site in the first sampling period, and biennially afterwards. Additional sampling may follow significant storm events.
- Water level, temperature and salinity measures will be obtained every 6 minutes, and downloaded and distributed quarterly (4 times a year). More frequent transfer of data can be accommodated if needed.

Personnel

- Senior Researchers: Jim Morris and Carolyn Currin
- Technicians: (3)

Parameters/Variables

- Sediment accretion rate (mm/yr)
- Tidal elevation (mean sea level) of benchmarks
- Surface elevation per 500-m^2 site (GIS layer, 2-cm vertical and horizontal accuracy)
- Sediment percent organic matter content
- Sediment particle size (% sand, % silt)
- Water level (relative to mean sea level), temperature and salinity
- Wave energy (kg-m s^3)

Field and Laboratory Procedures

Sampling Design and Collection.

SET installation and reading. SETs will be installed in coastal wetlands following the procedures for a Deep RodSET described in Cahoon et al. (2002). Marker horizons and estimates of marsh surface elevation will be obtained as described in Cahoon (1999). SETs have become a standard method for obtaining sediment accretion rates in coastal wetlands, including marshes and mangroves. Additional details on protocols, as well as a list of researchers and locations of SET installations around the world are available at http://www.pwrc.usgs.gov/set.

Sediment particle size and organic matter analysis. Sediment cores will be collected from locations where marsh species composition is obtained, and processed to determine sediment particle-size (% sand, silt-clay and gravel) and organic matter content, using standard methods.

Digital Elevation Models (DEMs). Protocols for the data acquisition and processing necessary to obtain high-resolution (< 2 cm vertical accuracy) have recently been developed by NOAA staff in collaboration with the U.S. National Geodetic Survey. This protocol has successfully provided GIS data layers for use in planning and monitoring marsh restoration projects in Maryland and North Carolina. (1) Obtain a high-resolution (1 cm vertical accuracy) benchmark within a marsh site by using a Real Time Kinematic D Geographic Positioning System (RTK DGPS). The RTK DGPS unit is deployed over the SET benchmark (described above). Vertical and horizontal position data from multiple four-hour data collection periods

(two or more weeks apart) are submitted to the NGS Online Positioning System (OPUS) program. This protocol yields an estimate of the x-y-x position of the SET benchmark (3/8" stainless steel rod) to 1 cm accuracy. This step allows us to establish a RTK DGPS master station at known position (SET Benchmark within mark site) using OPUS. (2) Collect a dense grid of marsh surface elevation data with a rover beacon mounted on a wheeled post, collecting position data at 1 sec intervals. Data collection transects within a 500 m^2 area are approximately 1 m apart. Data will be collected from MLLW to the upland margin along shorelines. Data is subsequently post-processed to provide a grid of elevation measures at > 2 cm vertical resolution. Data is mapped using ARCGIS Spatial Analyst. Changes in horizontal extent of vegetation or shoreline will be detected within 1.0 m accuracy (determined by transect location), and change in vertical elevations will be detected at 2 cm accuracy. Both Base maps and change analysis will be stored as ARCGIS data layers for each site.

The installation of a SET, in combination with the use of RTK DGPS technology and OPUS post-processing of data, effectively provides a tidal benchmark, which can be used in perpetuity as a reference point for elevation surveys. These are especially valuable in relatively remote locations within the estuarine intertidal.

In addition to the RTK DGPS methodology described above to obtain DEMs from SET benchmarks, we will explore the use of the Riegl LMSZ210ii 3D terrestrial laser scanner, which is being obtained by the Coastal Barrier module for mapping sediment profiles on barrier island beaches. The use of this instrument requires a fixed horizontal position (as a SET provides), and may provide the capability of measuring both bare earth elevations and plant canopy heights. This will be explored in Research Project CW-2 (*Forecast influence of natural and anthropogenic factors on estuarine shoreline erosion rates*).

Water Level/Tide gauge: The NOAA Beaufort Laboratory has recently worked with the NOAA COOPS to develop a protocol for installation of a temporary tide gauge in estuarine settings (NOAA, 2007). NOAA COOPS will also participate in the QA/QC and data analysis of water level data (NOAA, 2007).

Equipment Used.

Items marked with (*) are presently owned by the Coastal Wetlands Module Team.

- ROD SET reader
- YSI 660 Level Sondes (vented)
- Trimble 5800 Real Time Kinematic survey system (*)
- Multiple Trimble Pro XR DGPS (mapping grade) (*)
- Laser level Survey grade (*)
- Tablet PC (*)
- ARCGIS version 9.1 & 9.4 (*)
- Digital cameras (*)
- 22 and 20 foot boats and support equipment (*)

6.2.4.2.6 Data Analysis, Products, and Outcomes

Marsh accretion rates and elevation changes will be determined by comparing SET readings over time. Each SET reading consists of 36 observations, which is averaged to obtain a single estimate per SET. Differences between marsh surface elevation and accretion rates as determined by marker horizons will be used to estimate the role of shallow subsidence and sediment accretion in controlling marsh elevations (Calhoon et al., 1999; 2002). Spatial and temporal variation in marsh elevation change and accretion rates will be incorporated into models forecasting the response of coastal wetlands to sea level rise and nutrient additions (Research Project CW-1), and incorporated into forecasts of estuarine shoreline erosion (Research Project CW-2).

Water level, temperature and salinity data (6-minute frequency) will be made available to all team members in excel files. Water level data will be used in combination with marsh elevation distribution to calculate flooding times (hydroperiod) for coastal wetlands. Hydroperiod can be a key parameter controlling marsh production, sediment accretion rates, as well as biogeochemical processes and rates.

6.2.4.3 Marsh Groundwater and Nutrients

6.2.4.3.1 Objectives

Marshes of the NRE are uniquely positioned to interact with water and nutrient loads from the adjacent watershed (through shallow ground water and sheet flow) and from estuarine tidal waters (**Figure 6-8**). Hydraulic marsh flushing and nutrient loading are integrally linked to marsh productivity and sustainability. Water movement is the currency of exchange for contaminants and nutrients through marshes and riparian forests. Water and nutrient flux estimates (i.e., marsh water and nutrient budgets) through these environments to the adjacent estuaries will provide the timescale for transport, the significance of water and element exchange between upland ground water, marsh pore water, and the New River. Collectively these parameters help define the nutrient role of marshes within the NRE landscape and to determine the extent to which impacts to marsh sustainability will be manifested in estuarine water quality.

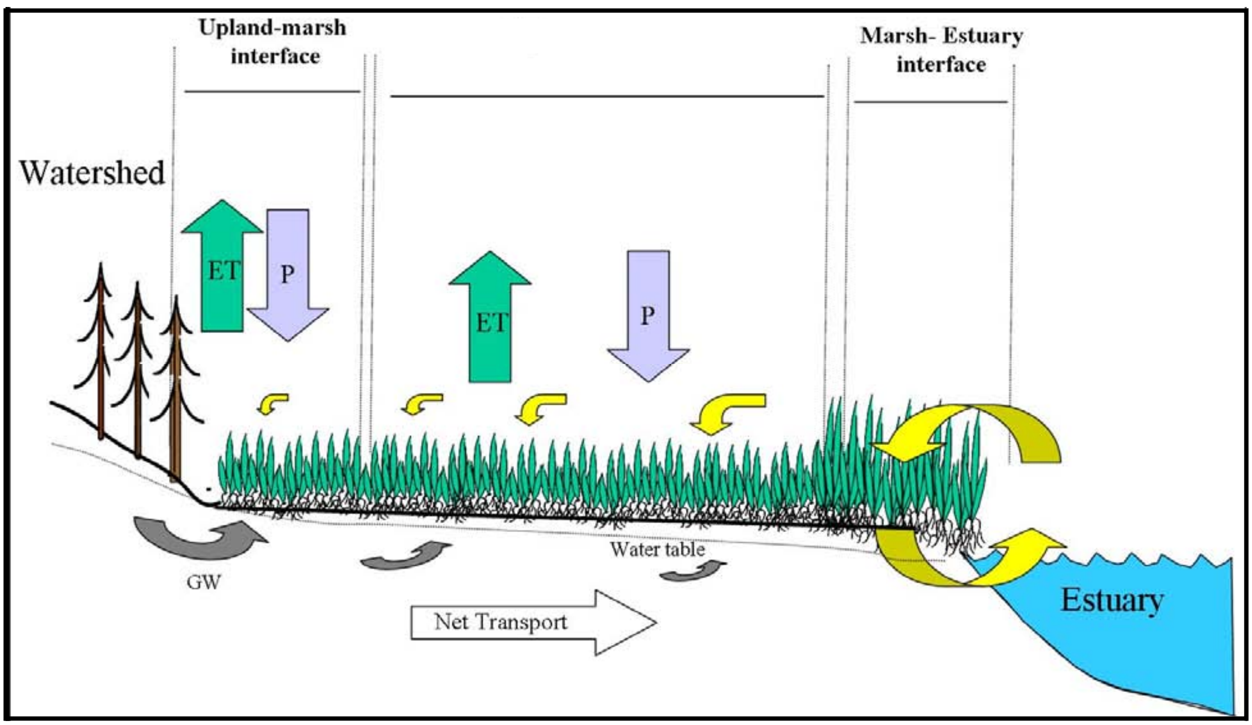


Figure 6-8. The marsh hydrological cycle includes groundwater (GW) flux from the upland, surface exchanges of ground water and flood water, drainage, evapotranspiration (ET) and precipitation (P).

Intertidal marshes serve as source, sink, and transformer of organic matter, nutrients and contaminants within the coastal landscape (Howes et al., 1996; Childers, 1993; Taylor and Allanson, 1995; Jordan et al., 1983) thereby linking coastal wetlands to the estuary. In addition, marsh elevation is maintained by balances between sediment deposition, primary production, and losses from decomposition. Monitoring of chemical indicators (e.g., nutrients that include N, P, and sulfur species) serve as markers that reflect relative changes in the balance between organic matter production and decomposition. Lastly, coastal wetlands are not a passive conduit for the movement of water and materials to the estuary, but rather a

biogeochemically reactive component of the landscape that serves to modify and/or attenuate nutrients or contaminants during transport (Harvey and Odum, 1990; Howes et al., 1996; Tobias et al., 2001 a,b,c). The nutrient chemistry and hydrologic monitoring provide essential parameters for assessing of the efficiency of marsh buffering capacity against anthropogenic nutrient loads as water transits from watershed to estuary and alteration of water quality during downstream transport.

6.2.4.3.2 Relevance to the Base

The results from this work will provide the baseline water budget and nutrient inventories for determining the extent of nutrient supply or uptake and hydraulic connectivity of the marshes to uplands and to the NRE. Consequently the work assess the relative importance (or not) of the marshes in maintaining the water quality of the NRE. The specific military drivers the benefit from this result are: (1) Ensure that MCBCL supports continued military training activities while complying with the CWA; and (2) Preserve the integrity of the amphibious maneuver areas in the NRE and adjoining training areas. Quantifying that exchange of water and fluxes of nutrients is necessary to assess linkages between terrestrial, wetland, and aquatic systems to determine how much the impacts on one component cascades to the other components.

This monitoring effort directly addresses the following management concerns of MCBCL:

- What is the impact of military activities and impact zones on shallow groundwater chemistry?
- What is the impact of groundwater withdrawal?

In addition, this data will support efforts to understand the linkage between changes in land use, coastal wetland distribution and elevation, and changes in estuarine water quality.

- How important are marshes as groundwater nutrient transformers?
- What nutrients limit primary production (impact on sedimentation rates)?
- Can marshes be utilized to treat wastewater, stormwater runoff or treated sludge?

6.2.4.3.3 Scale

Monitoring stations are distributed at watershed and installation scale.

6.2.4.3.4 Linkages within the Module and among other Modules' Monitoring Components

Monitoring of hydraulic throughput and marsh nutrient chemistry is linked to Research Project CW-1 and provides the infrastructure for Research Project CW-3. All monitoring activities in this monitoring program will be done at three of the marsh sites (Sites 2, 3, and 8) (see **Figure 6-7**). These sites are positioned to coincide spatially with sampling stations in the Aquatic/Estuarine Module monitoring. The proximity of these sites with those of the Aquatic/Estuarine Module will allow us to examine the variations in relationship between marsh sources or sinks of nutrients and localized changes in water quality of the adjacent estuary.

6.2.4.3.5 Methods

Spatial/Site Locations

Marsh nutrients and ground water will be collected at Sites 2, 3, and 8 (see **Figure 6-7**). Ideally, hydraulic and groundwater nutrient monitoring would be performed at all Coastal Wetlands Module monitoring sites, but this approach was cost prohibitive. Instead we have selected sites that represent low and high saline conditions. The salinity gradient is expected to serve as a proxy for different water contributions to the marsh, where presumably marshes further downstream will be dominated by tidal exchanges and those upstream receive larger hydraulic contributions from adjacent watershed. This site selection also encompasses sites of similar salinity (Sites 2 and 3) that differ substantially in upland land use. As stated

above the sites are also near monitoring stations in the Aquatic/Estuarine Module. Given the limited number of sites possible, our selection covers the expected range of variation in hydraulic parameters, adjacent upland land use, and provides for examination of marsh estuary interaction.

Temporal Considerations

Water levels are monitored continuously using remote loggers and commensurate with the tidal cycle. Pore water and ground water nutrients monitored seasonally as reflected by the timescale of changes in marsh production/decomposition and the seasonal variation in watershed hydraulic head.

Personnel

- Senior Researcher: Craig Tobias
- Technicians: (1)

Parameters/Variables

Chemical. Nitrate (NO_3^-), ammonia (NH_3^+), DON, soluble reactive phosphorus (SRP), sulfate (SO_4^{-2}), conductivity/salinity, ferrous (Fe^{+2}), hydrogen sulfide (H_2S), dissolved organic carbon (DOC), DO (all repeat measures)

Geological. Hydraulic gradient (repeat measures), hydraulic conductivity (determined initially)

Field and Laboratory Procedures

Sampling Design and Collection.

Hydrologic data field collection and laboratory methods are described in detail in Tobias et al. (2001b). Nutrient chemistry data field collection and laboratory methods are described in detail in Tobias et al. (2001a) and Tobias et al. (2001c). All nutrient chemistry collection and analysis methods adopted from EPA standard methods, *Methods of Seawater Analysis* (Parsons et al., 1984), or *Standard Methods for Water and Wastewater Analysis* (Eaton et al., 2005).

Equipment Used.

Hydrologic. Pressure transducers and loggers

Chemistry. Nutrient Auto Analyzer, Spectrophotometer, Fluorometer, High Temperature Catalytic DIC/DOC analyzer, Ion Chromatograph, pH meter, Winkler Titrator, Licor IR.

6.2.4.3.6 Data Analysis, Products, and Outcomes

Processing of the hydraulic and nutrient chemistry data under Research Project CW-3 was designed to be complementary with the data collected under the monitoring program. Water/nutrient fluxes will be estimated first by using a two-dimensional groundwater flow model calibrated with hydraulic head, hydraulic conductivity, and salinity. Secondly the use of a Coupled Water and Salt Mass Balance model will be constructed to independently quantify all components of the marsh water budget. Error estimates of the models will be achieved through a series of Monte Carlo simulations where all input parameters are varied simultaneous according to normally distributed random values that reflect their measured variance in the field. Sensitivity of the model output will also be determined through manipulation of each input parameter individually across two standard deviations of their observed means.

The coastal wetland piezometer networks established as part of the monitoring program will be instrumental in determining water flowpath direction, velocity, flux rates and water residence times.

Based on previous experience, the water budget of the marsh subsurface depends on tidal and shallow groundwater forcing functions. The magnitude of these forcing functions changes seasonally with the rise and fall of the water table, and tidal amplitude. Nutrient inventory changes primarily seasonally in response to temperature. Therefore the flowpath direction, velocity, fluxes, and residence times for water and nutrients can be correlated to water table height, tidal range, and temperature. Collectively these parameters should serve as a metrics or tool for future assessment of seasonal marsh connectivity to, and moderation of nutrient loads from, the adjacent watershed and estuary.

6.3 Coastal Barrier Module

6.3.1 Introduction

The coastal barrier ecosystem lies at the interface between the continental shelf in the ocean and the protected estuary, extending from the shore face toe at −10 meter water depth to the estuarine shoreline. This ecosystem encompasses the shallow subtidal and intertidal shore face, tidal inlet, backshore beach, aeolian dune, shrub zone, incipient maritime forest, and washover sand flat habitats. These habitats are defined by intrinsic ecological processes, but are linked together by sediment transport, nutrient exchange, and biological uses, each of which undergoes substantial change over multiple time scales. Sustaining the integrity of environmental and mission-related assets through an improved understanding of ecosystem response to natural and anthropogenic forcing is the main goal of coastal barrier monitoring and research activities. The Coastal Barrier Module will examine the coastal barrier of Onslow Beach from the New River Inlet to Browns Inlet, approximately 8 coastline miles.

The entire ecology of coastal barriers is organized directly and indirectly by the physical dynamics of meteorologically driven ocean forcing and the resulting sediment transport (Godfrey and Godfrey, 1976; Wells and Peterson, 1986) (**Figure 6-9**). Physical processes operating in the nearshore, including wind, waves, and currents, vary in magnitude on time scales from hours (e.g., coastal storms) and months (e.g., seasonal weather patterns) to years and decades (e.g., climate change). Sea-level rise is the background stage on which the physical processes are operating. The rate of rise is currently 3.7 millimeters/year at the NOAA tide gauge in Beaufort, NC, located 65 kilometers northeast of the study area, but this rate is predicted to accelerate because of global warming. Variations in the underlying geology and bathymetry of coastal areas, as well as the structure and topography of the subaerial beach influence how shorelines will respond (i.e., accrete, erode, change in sediment type) to different physical forcings (McNinch, 2004; Rodriguez et al., 2004).

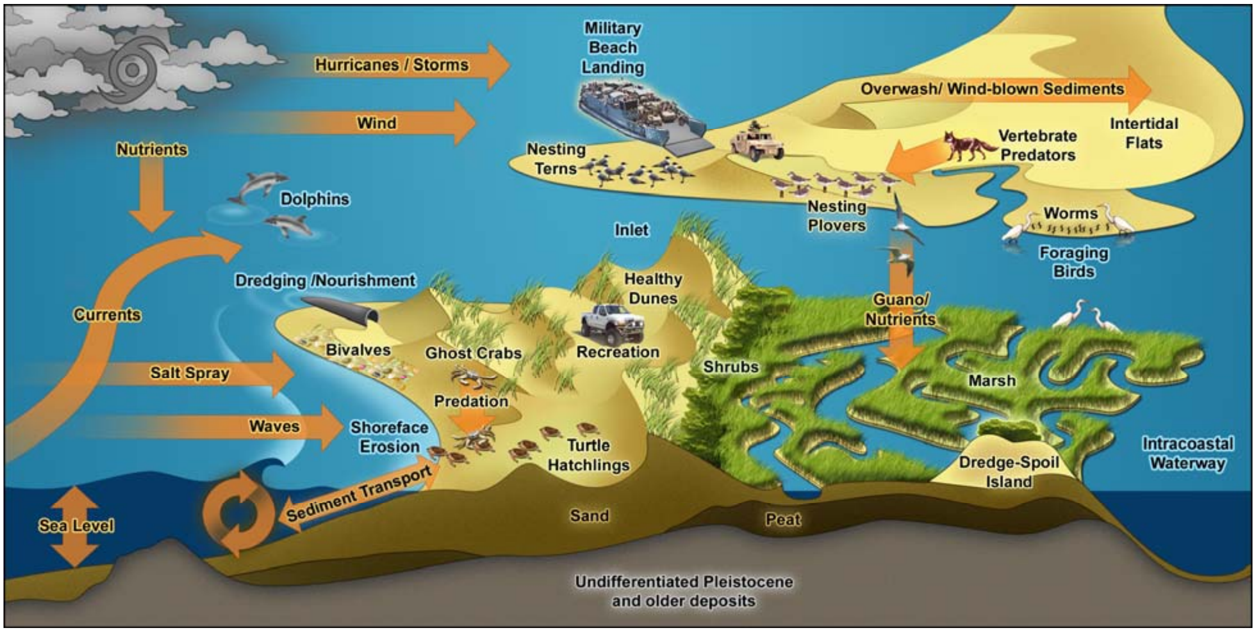


Figure 6-9. Conceptual model for the Coastal Barrier Module.

The intertidal portion of the shore face enjoys high production of characteristic invertebrates, such as coquina clams and mole crabs, because of the high flux of suspended diatoms from oscillating wave action on shore. The high densities of these invertebrates qualify the intertidal beach as a key habitat, one that supplies food for abundant and valuable surf fishes, crabs, and shorebirds, including the piping plover (Federally Threatened), red knot (Candidate Species for Listing), and many other state and federal bird species of concern (Brown and McLachlan, 1990; Fraser et al., 2005; Karpanty et al., in press). Threatened species of sea turtles lay eggs on the high beach during summer, which require about 60 days to develop and hatch. Coastal barrier vegetation affects nesting site selection of sea turtles and shorebirds, other ground-nesting seabirds like terns, and waders. Predators subsequently influence the distribution, abundance, and breeding success of nesting sea turtles and nesting and migratory shorebirds and terns. Depredation of sea turtles and birds may alter rates of guano deposition on the barrier island and impact nutrient cycling, which in turn modifies the barrier vegetation. More densely vegetated coastal barriers are better at trapping wind-blown sands, and thus build and stabilize the barrier island land mass, providing greater resiliency against storm damage and island overwash and erosion.

Low-lying coastal barriers, such as those of MCBCL, experience frequent overwash during storms. This process reinitiates the succession of dune and shrub-zone plant communities, provides new habitat for bird nesting and foraging, and extends and revitalizes salt marshes when overwash progresses across the island to the sound shoreline. Rare beach plants are sensitive to storm impacts, and some species, such as the seabeach amaranth, may even be enhanced by such perturbations. The dune and shrub plants of the coastal barrier suffer physiological stress from wind-borne salt spray, yet receive limited nutrients from that same source and atmospheric deposition (Au, 1974). The inlets of coastal barriers are especially dynamic, and storm overwash at inlets plays an important role in maintaining flat and sparsely vegetated areas suitable for nesting and foraging by piping plovers, other shorebirds, terns, and gulls (Fraser et al., 2005).

6.3.2 Coastal Barrier Module Monitoring Objectives and Activities

The Coastal Barrier Module monitoring program will measure, analyze, integrate, synthesize, and model physical, geological, and biological processes that operate from the ocean at -10 m water depth (the depth of "closure") to the back-barrier shoreline from the New River Inlet at the northeastern end of North

Topsail Beach including Brown's Inlet, approximately 8 coastline miles (**Table 6-7**). The coastal barrier ecosystem is strongly influenced by meteorologically driven physical forcing, which has important short time scales of storm (hurricane and northeasters) events, seasonal signals of changing wind fields, and multi-annual time scales as sea level and frequency of intense storms both increase. This physical forcing transports sediments, driving changes in bathymetry, subaerial topography, shoreline position, and the presence, location, and extent of tidal flats on the inlet and back-barrier shores. Winds also mobilize sands on coastal barriers, and emergent vegetation acts to trap those wind-blown sands and thereby elevate the island land mass and render it more resilient to storm damage, overwash, and erosion of land area. The sediment mobility and changes in its size distribution and mineralogic composition help determine the abundance and composition of the benthic invertebrates on the ocean beach and on sand flats on the inlet and back-barrier shores. These benthic invertebrates provide the prey on which the entire surf fish and shorebird community depends: thus this is the trophic base that dictates habitat quality for species of importance that are managed by humans. Sea turtles nest on the high beach and their nesting success is strongly influenced by physical processes: storms can wash away nests or drown developing sea turtles in the nests. Predation on sea turtle eggs and hatchlings and on shorebird and seabird eggs and nestlings forms a top-down control on success of these species that can be more important than the bottom-up physical forcing. Because ground-nesting shorebirds, terns, gulls, and black skimmers choose to nest in areas of sparse vegetation to allow detection and avoidance of predators yet fertilize the vegetation by guano deposition, storm intervention plays an important role in restoring prime nesting grounds.

Table 6-7. Coastal Barrier Module Monitoring Components

Component	Variable(s)	Spatial Scale	Temporal Scale
Meteorology (Ocean)	Air temperature, wind speed, air pressure, solar radiation, wind direction	2 stations: 5 and 25 miles seaward of the New River Inlet	Continuous
Hydrodynamics	horizontal and vertical wave velocity, wave heights, and period, direction; currents; water temperature	2 stations: 5 and 25 miles seaward of the New River Inlet	Continuous
	horizontal and vertical wave velocity, wave heights, period, and direction	2 stations: 500 m seaward of Riseley Pier and North Topsail Beach	Continuous
	Tide data	Acquired from NOAA sites at Wilmington, NC; Charleston, SC; Norfolk, VA	Continuous
	shoreline position, sand bar position and morphology; nearshore wave period, direction, and height	Entire length of authorized beach and individual sites	Every 3 years (entire); Semiannually and before/after storms (site specific)
Geomorphology	Shoreface bathymetry	Across the nearshore (2–10 m) depths throughout region of barrier island including New River Inlet and Brown's Inlet and individual sites	Every 3 years (entire); Semiannually in Years 1, 3, and 4 (site specific)
	Barrier morphology	Throughout authorized region of barrier island from the dune to the shoreline and individual sites.	Every 3 years (entire); Semiannually and before/after storms (site specific)
Sedimentology	Compaction, texture and composition	20 samples from each of the 6 sites	Semiannually (May/Sept); before/after storms

Component	Variable(s)	Spatial Scale	Temporal Scale
Biology	Benthic invertebrate abundance and biomass by size class and community structure	2 replicate vertical transects from each of the 6 sites	Semiannually; before/after storms
	Shorebird and seabird abundance and community structure	Entire length of Onslow Beach, New River Inlet and Brown's Inlet shoreline	Every 10 days (collected by MCBCL)
	Dune, shrub, and marsh plants aerial cover, vegetation height, and surface elevation	Vertical transects at 6 sites and aerial photography of entire length of Onslow Beach, New River Inlet and Brown's Inlet shoreline	Vertical transects:. Years 3 and 4; Aerial photography: annually
	Site selection for sea turtle nests, false crawls, and success of nesting effort	Nesting and false crawls recorded along entire length of Onslow Beach, New River Inlet and Brown's Inlet shoreline	Nesting and false crawls assessed daily in season (collected by MCBCL)

Superimposed upon this background of natural physical, geological, and biological processes that interact to determine the state, health, and persistence of the barrier island ecosystem are human interventions. Such human interventions on Onslow Beach include recreational off-road driving, amphibious training, dune restoration of topography and vegetation, inlet dredging, augmentation of predatory vertebrates like raccoons, and potentially beach nourishment or application of alternative protections against shoreline erosion. The goal of the monitoring activities for the Coastal Barrier Module is to make those necessary measurements and observations that allow isolation and integration of human-derived (including Base activities) and natural processes to understand the dynamics and health of the coastal barrier ecosystem. The focus is on outputs that serve to identify how those components of the ecosystem of most concern to MCBCL can be most successfully managed and optimized. Fulfilling this goal requires not only measurement of conditions and processes from physics to biology but also the analysis, synthesis, integration, and modeling of the information.

The information derived from these basic research studies will be integrated into the ecosystem-based synthesis along with the results of coupled and monitoring of meteorology, physics, geology, benthic biology, shorebird use, vegetation, and land mass geomorphology to provide the basic scientific platform from which to answer applied questions of management of Base assets and activities to maximize military training use. In these syntheses, we will also incorporate results of the historical analysis of shoreline change from Research Project CB-2 and historical monitoring data by the Base for shorebirds (6 years) and sea turtle nesting (> 20 years).

The objectives of the Coastal Barrier Module monitoring strategy are:

- Create an integrated ecosystem understanding of how meteorology, physics, bathymetry, geomorphology, benthic prey resources, plant cover, sea turtle nesting, shorebird foraging and nesting, and predator impacts interact to determine the health and state of the coastal barrier ecosystem;
- Differentiate impacts of natural from Base-derived ecosystem forcing mechanisms;
- Improve management capacity for MCBCL's coastal barrier system;
- Ensure sustainability of Base training uses into the future; and
- Meet MCBCL's commitments to sustaining critical natural resources.

A holistic monitoring program that through basic research identifies indicator variables will lead to a tiered data management system in the coastal barrier ecosystem. Monitoring activities will center on

quantifying the physical (e.g., tides, waves, and currents), geological (e.g., sediment texture and composition), geomorphological, and biological changes to MCBCL's coastal barrier ecosystem because these interacting processes define health and sustainability of the barrier itself and its ecosystems. To differentiate between natural and anthropogenic (Base derived) impacts on the coastal-barrier ecosystem, monitoring activities will produce replicated measurements of the intensity of disturbance during amphibious landings and off-road recreational driving against which to compare replicated measurements of the geological and biological response variables. A spatial pattern exists along the length of Onslow Beach, with a continuous dune line, medium sand sediments, low historical erosion rates, and little human disturbance at the north end of the barrier, as compared to scattered dunes, coarse sand and shell sediments, high erosion rates, and multiple human disturbance agents in the central zone and at the southern end of the barrier. Our strategy for determining the consequences of Base activities will involve making observations to quantify intensity of passage of amphibious landing craft, vehicles, and personnel. We will conduct measurements that will allow us to use sediment compaction and surface roughness to integrate the contributions of vehicles of different types and sizes. These observations will then be used to calibrate the Base records of numbers and locations of amphibious training exercises and numbers of vehicles and troops involved. Results will be used to help select 2 focus sites that experience, and in which we quantify, intense activity from amphibious landing exercises. Similarly, we will make observations of intensity of off-road recreational vehicle driving and select 2 focus sites in which we have quantified driving intensity and calibrated compaction and surface roughness. A final 2 focus sites will represent controls that do not experience off-road driving or amphibious landings. By understanding processes that drive the ecosystem state, we will be able to disentangle these differences and gain understanding of the degree to which such differences are natural versus induced by specific Base activities (amphibious landings and off road recreational driving) and from that develop appropriate management recommendations. In addition, observations will be made on an event scale to understand how major storms influence this ecosystem, both directly and by interacting with anthropogenic influences, and how the system recovers. For example, we expect that storm overwash will vary as a function of the degree to which the dune elevations have been diminished by base activities. The frequency of sampling activities will vary from continuous to event scale to seasonal, to (multi)annual, depending on the type of data being collected, Base activities, and the passage of storms.

The physical processes of the coastal system, including wind, waves, and currents will be monitored from ocean sensors. These processes vary in response to meteorological (e.g., weather) conditions, anthropogenic activities, and feedback from changing nearshore morphology. Physical processes interact with the geology and vegetation of the area resulting in morphological changes. Morphologic changes will be measured remotely using acoustic and laser-ranging techniques, while changes in biota will be quantified by sampling and observation directly in the field and indirectly from aerial photographs. Biota is impacted by physical processes (e.g., wind shear, current velocity), anthropogenic perturbations (e.g., beach nourishment), and geomorphologic changes (e.g., sediment transport, erosion and accretion). Changes in plant cover and height, which will be measured directly in the field, also influence coastal morphology. Process-based monitoring will not only document changes to the coastal barrier ecosystem through time, but will allow the observed changes to be linked directly to their associated forcing mechanism(s) thereby improving development of indicators of ecosystem health and identification thresholds of ecosystem state changes, and allowing for modeling to predict future changes.

Table 6-8 summarizes the estimated level of effort for each of the key personnel during the first four years of Phase II for the monitoring activities previously listed in **Table 6-7**. A specific list of the personnel for each monitoring activity is located within the Methods section of each monitoring activity described in Section 6.3.4 (*Coastal Barrier Module Monitoring Components*).

Table 6-8. Coastal Barrier Module's Estimated Staffing of Monitoring Activities

Personnel	Time in months/year			
	Year 1	Year 2	Year 3	Year 4
Pete Peterson	1	1	1	1
Tony Rodriguez	1	1	1	1
Rick Luettich	1	1	1	1
Jesse McNinch	1	0.5	1	1
Sarah Karpanty	0.5	-	-	-
Jim Fraser	0.5	-	-	-
Post-doctoral Students (2)	4	4	16	16
Graduate Students (3)	12	36	12	12
Technicians (3)	6	6	13	13

6.3.3 Benefit to MCBCL

The goal of the Coastal Barrier Module monitoring is to make those necessary measurements and observations that allow isolation and integration of natural and Base induced processes to understand the dynamics and health of the coastal barrier ecosystem. Monitoring efforts will address MCBCL's most pressing management needs, including beach erosion and conservation of habitat for threatened and endangered species on the barrier while providing important data for the research projects. Existing barrier management will be enhanced by (1) Identifying the underlying causes accelerating beach erosion on Onslow Beach; (2) Forecasting beach erosion if current management does not change; (3) Developing a beach-erosion plan that provides management alternatives to counter beach erosion; (4) Developing efficient monitoring protocols and conservation management procedures for shorebirds and seabirds; (5) Designing the most efficient use of predator trapping resources to minimize the frequency of trapping and the co-occurrence of trapping efforts with human uses of the barrier; and (6) Developing and testing indicators of barrier island ecosystem state and health that can be easily measured by Base personnel in the future after project completion.

6.3.4 Coastal Barrier Module Monitoring Components

6.3.4.1 Hydrodynamics (Oceanographic data)

6.3.4.1.1 Objectives

Oceanographic data are archived and currently collected as part of the Coastal Ocean Research Monitoring Program (CORMP). These data consist of water velocity, atmospheric information, and water hydrography on the continental shelf seaward of New River Inlet. Analysis of archived data is required to understand the "basic" physical characteristics of flow in this region, such as dominant tidal species, and contribution of atmospheric forcing to variability in the flow field, and to calibrate hydrodynamic models. The currently available data need to be analyzed to support the overarching goal of understanding the physical processes as they relate to barrier island sustainability.

6.3.4.1.2 Relevance to the Base

The information learned from analysis of these data is directly related to Onslow Beach erosion, a high priority need of MCBCL.

6.3.4.1.3 Scale

The data are on the plot scale, but analysis may show that they could be applied to the regional level.

6.3.4.1.4 Linkages within the Module and among other Modules' Monitoring Components

Analysis of these data will aid in the calibration of both the finite element model, Advanced Circulation (ADCIRC), and for the Simulating Waves Nearshore (SWAN) model for this region. Both of these models directly aid in the objective of constraining the hydrodynamic processes at the barrier, which is the principle driver of morphologic and habitat change. Additionally, the ADCIRC model of the region may be employed by the Aquatic/Estuarine Module to understand how the circulation within the estuary affects water quality and benthic habitat. Special adaptations of the ADCIRC model may also be used by the Coastal Wetlands Module to understand the effects of hydrodynamics on marsh erosion in that habitat.

6.3.4.1.5 Methods

Spatial/Site Locations

Instrument locations are already established and are shown in **Figure 6-10**. The archived data is approximately 20 and 25 miles seaward of the New River Inlet. The current data are available from instruments located approximately 5 miles seaward of the New River Inlet.

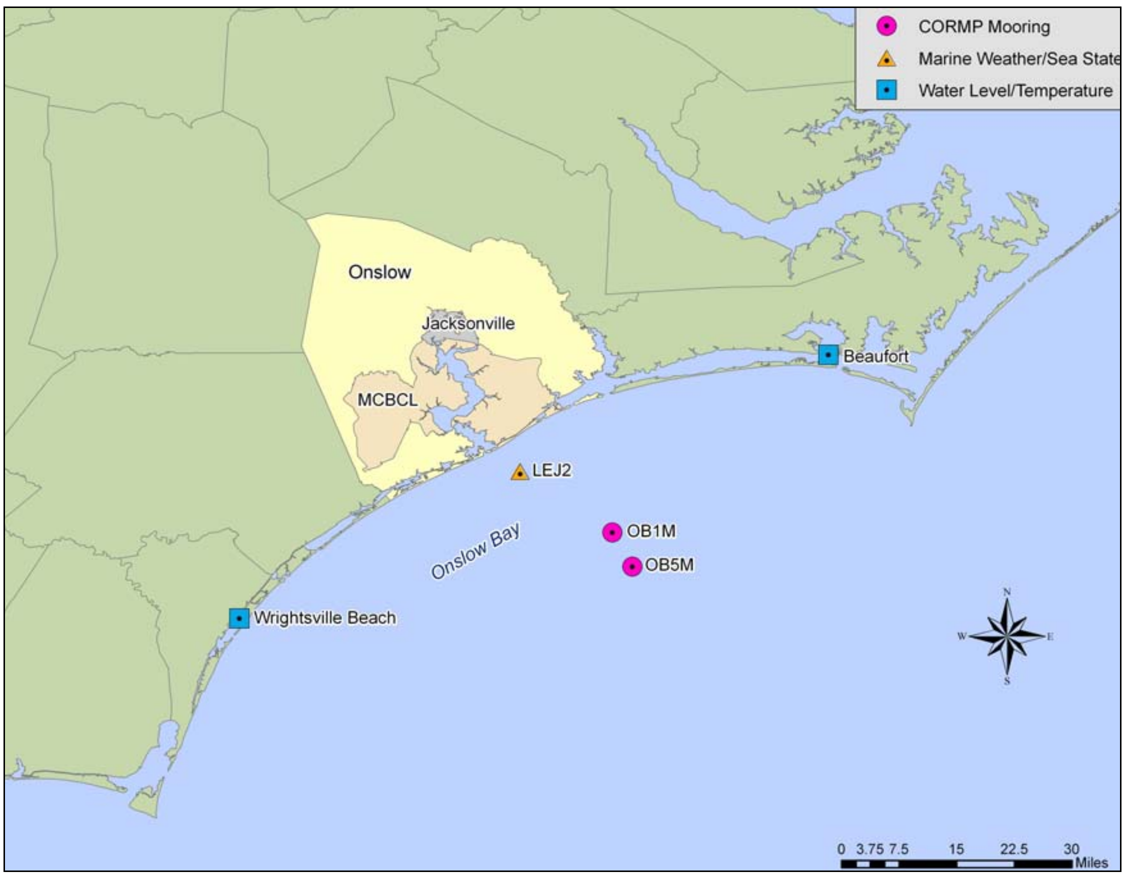


Figure 6-10. Hydrodynamics (oceanographic) monitoring stations.

- **Buoy Data.** Acquire oceanographic data from CORMP
  - LEJ2 buoy data (5 miles from New River Inlet): air temperature, wind speed, wind direction, barometric pressure, humidity, solar radiation, surface water temperature, surface current speed and surface current direction, surface salinity, wave height, and dominant wave period.
  - OB1M mooring (20 miles from New River Inlet): water speed and direction

  - OB5M mooring (25 miles from New River Inlet): water speed and direction through out water column, thermistors
  - Analyze velocity and hydrodynamic data to determine key driving frequencies and compute correlations between data to establish causative relationships.
- **Tide Gauge Data.** From Coastal Wetlands Module monitoring effort (tide gauge in NRE) and NOAA acquired tide gauge data in Wrightsville Beach, NC and Beaufort, NC to derive background rates of sea-level rise.

Temporal Considerations

Velocity data acquired with an upward looking ADCP are collected between 15 min and 1 hr, depending on when the instrument was deployed.

Personnel

- Senior Researcher: Rick Luettich

Parameters/Variables

Data collected vary from mooring to mooring, but include, horizontal water velocities throughout the water column, significant wave height, dominant wave direction, water temperature, salinity, wind speed, wind direction, solar radiation, air temperature, and air pressure.

Field and Laboratory

Analysis of the data will require a high speed computer with at least 80Gb of hard drive space. Required software includes MATLAB[@] with the associated toolboxes.

Data Management

These data are currently being held with the CORMP research group and may be accessed via the CORMP Web site.

6.3.4.1.6 Data Analysis, Products, and Outcomes

Buoy and tide gauge data will be integrated with data from the ADCP. Traditional time-series analysis, as well as wavelet analysis techniques will be used to analyze these and subsequent data. The main focus will be on deciphering key tidal frequencies, as well as local and remote atmospheric forcing.

From this analysis, we expect to know the important tidal frequencies, their amplitudes and their contributions to the variability of flow within this system. Additionally, low-frequency flow variations will be determined and correlated with atmospheric data.

This information ties directly with the ADCIRC model set-up of the region as knowing the correct tidal frequencies is imperative for the model to produce comparable results. A physics-based, hydrodynamic-sediment transport model (modeling relevant physics of sedimentation or MORPHOS), currently in development at the USACE in collaboration with the Senior Researcher (Rick Luettich), will be used to simulate how longshore transport in 20-m grid cells and the shoreline position will change in response to extreme storms. Other products will include flow, wave, and water-level predictions for the area.

6.3.4.2 Hydrodynamics (ADCP)

6.3.4.2.1 Objective(s)

Collection of water velocity data concurrently with barrier island sampling is crucial for understanding the processes behind the changes in barrier island morphology. These data explain specifically what the conditions were during and between sampling. Analysis of the data provides information about the

"basic" physical characteristics of flow in the region. These data will also be used to verify the ADCIRC and SWAN hydrodynamic models of the region, which are based on the offshore buoys. While the ADCPs will only be deployed during DCERP, the offshore buoy monitoring stations will persist indefinitely. Consequently, our goal is to enhance the capability of using the offshore information on wave climate to predict hydrodynamic conditions at Onslow Beach.

6.3.4.2.2 Relevance to the Base

The information obtained from analysis of these data are directly related to Onslow Beach erosion and habitat change, a high priority need of MCBCL.

6.3.4.2.3 Scale

Through modeling efforts, data from both monitoring sites will be extrapolated throughout the entire area.

6.3.4.2.4 Linkages within the Module and among other Modules' Monitoring Components

The analysis of the data collected from these instruments will aid in the calibration of both the finite element model ADCIRC set-up for this region and for the wave model, SWAN. Both of these models directly aid in the objective of constraining the hydrodynamic processes at the barrier, which is the principle driver of morphologic and habitat change. Additionally, the ADCIRC model of the region may be employed by the Aquatic/Estuarine Module to understand how the circulation within the estuary affects water quality and benthic habitat. Special adaptations of the model may also be used by the Coastal Wetlands Module to understand the effects of hydrodynamics on marsh erosion in that habitat.

6.3.4.2.5 Methods

Spatial/Site Locations

ADCPs will be located 500m seaward of the most seaward remaining piling of Riseley Pier on Onslow Beach and a similar distance offshore at North Topsail Beach. The instruments will be self-contained units and diver-deployed.

Temporal Considerations

The ADCPs will be deployed and re-deployed bi-monthly for the duration of the monitoring period. Data ensembles, representing the average horizontal and vertical flow velocities will be collected every 15 minutes. The wave array ADCP from Teledyne RD Instruments allows for the simultaneous sampling of wave burst and the standard current profiles. It is essential that at least a yearly record of flow data is acquired to discriminate the atmospheric drivers from other drivers.

Personnel

- Senior Researcher: Rick Luettich
- Post-Doctoral Research Associate: Janelle Fleming
- Technician: Tony Whipple

Parameters/Variables

The ADCPs will measure the horizontal and vertical water velocities in 0.25m bins from the head of the instrument to the near surface. Wave data such as significant wave height, maximum wave height, mean wave height, wave period, and wave direction, will be collected.

Field and Laboratory Procedures

Deployment of ADCPs requires the use of an oceangoing vessel and university-approved scientific divers familiar with deploying these stands. Data will be taken continuously then downloaded into electronic data files for analyses and modeling.

Data Management

The raw data will be entered into the DCERP data and information management system. Units are generally in terms of meters/second, meters, and seconds. All deployment information and statistics will be included.

6.3.4.2.6 Data Analysis, Products, and Outcome

ADCP data will be integrated with buoy and tide gauge data. Traditional time-series analysis, as well as wavelet analysis techniques will be used to analyze these and subsequent data. The main focus will be on deciphering nearshore hydrodynamics. From this analysis, we expect to know the important tidal frequencies, their amplitudes and their contributions to the variability of flow within this system.

This information ties directly with the ADCIRC model set-up of the region as knowing the correct tidal frequencies is imperative for the model to produce comparable results. A physics-based, hydrodynamic-sediment transport model (MORPHOS), currently in development at the USACE in collaboration with the Senior Researcher (Rick Luettich), will be used to simulate how longshore transport in 20-m grid cells and the shoreline position will change in response to extreme storms. Other products will include flow, wave, and water-level models for the area.

6.3.4.3 Hydrodynamics (Mobile Radar)

6.3.4.3.1 Objectives

The overarching purpose of the mobile radar component is to deploy a monitoring technique that will bridge the gap between long-term morphological responses of the beach (e.g., erosion over a decade) and hydrodynamic observations-modeling of short-term events (e.g., storms), and ultimately, enable us to distinguish the relative importance of multiple causes (e.g., natural versus training exercises) of erosion across the barrier island beach.

6.3.4.3.2 Relevance to the Base

The mobile radar monitoring will provide real-time maps of the sand bars in the surf zone (and inlet region) and the shoreline along the entire length of the field site, as well as wave measurements (direction, period) in the nearshore. This can be conducted quickly and in any weather conditions and will be instrumental in mitigating beach erosion because we will be able to precisely measure key mechanisms relevant to sediment transport and beach erosion during storms.

6.3.4.3.3 Scale

The field site will span the accessible regions of the barrier beach from the foreshore swash zone to the outer surf zone. The entire region will be mapped at 1–2 m spatial resolution and mapping will be repeated semi-annually, as well as replicate pre- and post-storm events and during select amphibious exercises.

6.3.4.3.4 Linkages within the Module and among other Modules’ Monitoring Components

The hydrodynamic measurements and modeling activities will utilize the mobile radar measurements as part of its calibration and verification of the sediment transport model (MORPHOS). These measurements will also bridge the gap between beach and nearshore mapping that will be conducted annually and will

identify regions that are the most dynamic and potentially problematic with respect to overwash and erosion. These activities will provide essential information on nearshore sediment dynamics during storms and across seasons for Research Projects CB-1 and CB-2.

6.3.4.3.5 Methods

Spatial/Site Locations

The mobile radar measurements will be conducted along the entire length of the Onslow Beach, New River Inlet and Brown's Inlet shoreline during Years 1 and 4. Data will be collected semiannually and before and after replicate storms from 6 focus sites, 2 of which experience off-road driving, 2 amphibious landings, and 2 limited human disturbance (**Figure 6-11**). The radar will be towed along the upper beach using a small beach vehicle supplied by MCBCL.

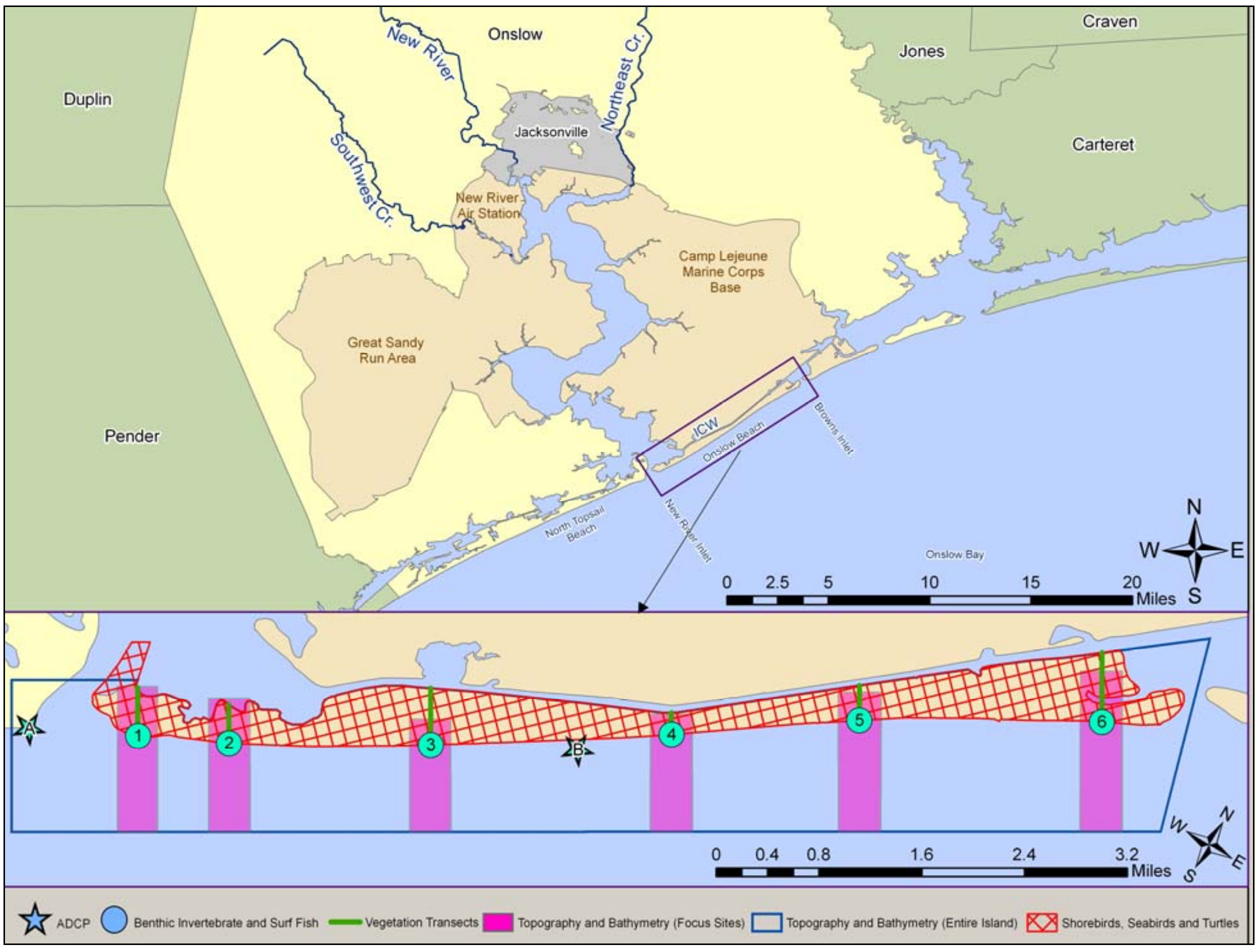


Figure 6-11. Coastal Barrier Module monitoring efforts.

Temporal Considerations

Measurements will be collected every 3 years from the entire barrier and semi-annually each year in the spring and fall (likely May and September) at the 6 focus sites as well as before and after several replicate storm events. In addition, we will conduct observations before and after amphibious assault exercises to measure the resulting changes in nearshore bathymetry.

Personnel

- Senior Researcher: Jesse McNinch

- Post-docs: Heidi Wadman
- Technician: 1

Parameters/Variables

- Shoreline position (x, y, z) at 2m spatial resolution
- Sand bar position and morphology (x,y) at 2-m spatial resolution
- Nearshore wave parameters—wave period, direction, approximated height

Field and Laboratory Procedures

Sampling Design and Collection. Radar and ancillary equipment (e.g., computer, motion sensor) will be towed along the beach with a small beach vehicle. Radar reflectance will be measured and converted into wave properties and nearshore bathymetry using proprietary software.

Equipment Used.

- BASIR (4 KW radar)
- Gator (ATV-like beach vehicle)
- RTK GPS

Data Management

Raw and processed data, including bathymetry and wave characteristics (period, height, and direction) will be integrated into the DCERP data and information management system.

6.3.4.3.6 Data Analysis, Products, and Outcomes

Radar data will be used to develop maps of the shoreline and nearshore sandbars including bathymetry. These data will be presented as geo-rectified maps using established horizontal and vertical datums. Effort will be made to integrate with Base personnel such that observations can coincide with relevant Base use of the beach and surf zone. Furthermore, these data will be instrumental in understanding sediment transport pathways, and post-storm or post-operations recovery of the beach.

6.3.4.4 Shoreface Bathymetry

6.3.4.4.1 Objectives

The primary objective of the shoreface mapping is to assess the morphology, sediment distribution, and framework geology of the barrier island nearshore. Historic work (Crowson, 1980; Robertson, 1994; Riggs et al., 1995; Johnston, 1998; Riggs and Cleary, 1998; Cleary and Riggs, 1999; Filardi, 1999; Sault, 1999; Sproat, 1999; Wise, 1999) provides a comprehensive basis for the development of our synthetic monitoring of how sediment dynamics influence the bathymetry and island morphology as a function of the framework geology and physical forcing. Recent studies have established the importance of these geologic parameters on beach erosion and these must be quantified before beach use/management strategies can be developed.

6.3.4.4.2 Relevance to the Base

The barrier beach has been identified by Base personnel as a critical part of their training program (amphibious exercises) and warrants management strategies that will enabled continued use of the beach while maintaining some semblance to a naturally occurring barrier beach. The shoreface mapping program will monitor bathymetry that will be used in modeling shoreline change (MORPHOS and Research Projects CB-1 and CB-2). This effort will be an integral part of mitigating barrier beach erosion.

6.3.4.4.3 Scale

The nearshore will be mapped from the nearshore sand bar (2–3 meter depths) to the outer surf zone (10–12 meter depths).

6.3.4.4.4 Linkages within the Module and among other Modules' Monitoring Components

These data will link with the barrier mapping, radar beach and sand bar mapping, and hydrodynamic (ADCP and modeling) monitoring activities. Bathymetric changes around inlets influence tidal flow in the estuary and will be used in the estuarine circulation modeling of the Aquatic/Estuarine Module. Changes in bathymetry at the New River Inlet in the south and Brown's Inlet in the north reflect the longshore sediment transport that connects Onslow Beach to the neighboring islands.

6.3.4.4.5 Methods

Spatial/Site Locations

Swath bathymetry, side scan sonar, and shallow sub-bottom profiles will be collected across the nearshore (2–10 meter depths) of the Onslow Beach, New River Inlet, and Brown's Inlet shoreline (**Figure 6-11**).

Temporal Considerations

Nearshore mapping will be conducted in Years 1 and 4 across the entire length of the Onslow Beach, New River Inlet and Brown's Inlet shoreline. Data will be collected semiannually during Years 1, 3, and 4 from 6 focus sites, 2 of which experience off-road driving, 2 amphibious landings, and 2 with limited human disturbance

Personnel

- Senior Researchers: Jesse McNinch
- Graduate Student: Amy Foxgrover
- Technicians: vessel technician

Parameters/Variables

Nearshore bathymetry (x,y,z), side scan sonar (x,y, amplitude), seismic reflection profiles to assess sediment thickness and sediment volume.

Field and Laboratory Procedures

Sampling Design and Collection. Bathymetric data will be collected using a interferometric swath sonar system, which operates continuously from a specially designed vessel capable of accessing the outer sand bar and beach progressing at 4.0 knots. Sub-bottom data will be collected concurrently using an Edgetech SB-512 chirp seismic system. Data will be collected during calm sea conditions.

Equipment Used. Surf vessel, swath bathymetry system, sub-bottom profilers, side scan sonar, RTK GPS

Data Management

Raw and processed data including geo-referenced bathymetric maps and structure maps of the underlying geology will be integrated into the DCERP data and information management system.

6.3.4.4.6 Data Analysis, Products, and Outcomes

Shoreface bathymetry and seismic maps will be provided as maps in geo-rectified formats using established horizontal and vertical datums. Parameters, such as sediment volume or 3-dimensional

bathymetry, will be instrumental in understanding littoral processes and the roles of natural forcings versus Base use. Furthermore, these data will be an integral component to developing the models (short-term and long-term) to predict beach change.

6.3.4.5 Barrier Morphology

6.3.4.5.1 Objective(s)

The purpose of monitoring barrier morphology is to ensure sustainability of Base activities into the future and to improve management capacity for MCBCL's coastal barrier system. The barrier ecosystems are defined by their morphology. Morphologic changes in the coastal barrier indicate erosion, accretion, and vulnerability to extreme events.

6.3.4.5.2 Relevance to the Base

This monitoring component will help mitigate barrier erosion. Long-term erosion rates (1938–1992) vary significantly along short distances (Benton et al., 1993). For example, erosion rates decrease from > 6 m/yr, adjacent to the New River Inlet, to < 1 m/yr, at the old Riseley Pier 5.8 km to the southwest. To preserve the land mass in a form that sustains Base activities into the future, (1) Erosion rates need to be quantified, (2) Acceleration or deceleration in erosion rates needs to be quantified, (3) The spatial variability in erosion rates needs to be mapped, and (4) it is necessary to understand the causes of and respond to erosion-rate variability.

Part of the coastal barrier is important for amphibious military training. During training exercises the ecosystem receives significant boat, foot, and vehicular traffic. However, the underlying geology and natural sediment-transport pathways may overwhelm any contribution to erosion from anthropogenic stressors but this relationship needs to be examined.

6.3.4.5.3 Scale

The topography of the entire barrier (ocean shoreline to dune) and 6 focus sites (ocean shoreline to ICW shoreline) will be mapped at sub-cm spatial resolution (horizontal and vertical).

6.3.4.5.4 Linkages within the Module and among other Modules' Monitoring Components

Change in barrier morphology affect sediment delivery to the coastal wetlands and the hydrodynamics of the estuary. Extensive coastal wetlands exist on the landward side of the barrier and movement of the shoreline directly affects the function of the coastal marsh environment. For example, wind-transported sand from the barrier and sand washed over the barrier during storms are important sediment sources for coastal wetlands that help this environment "keep up" with sea-level rise. Biota is impacted directly by geomorphologic changes (erosion and accretion) and there is a feedback between changes in morphology and physical processes. For example, the gradient of the foreshore defines the width of tidal inundation.

6.3.4.5.5 Methods

Spatial/Site Locations

The topography from the ocean shoreline of Onslow beach to the dune, excluding the no-go impact zone in the north, will be mapped once every 3 years. This activity will coincide with the bathymetry mapping effort. These two datasets will be merged to enable us to characterize the entire volume of the barrier. Data will be collected from the ocean and lagoon sides of the barrier semiannually from 6 focus sites, 2 of which experience off-road driving, 2 amphibious landings, and 2 limited human disturbance (see **Figure 6-11**). These sites correspond will all of the other monitoring activities in the coastal barrier module and two coastal marsh sites.

Temporal Considerations

Morphology will be assessed every 3 years (the entire beach), semiannually (6 focus sites), and before and after replicate storm events (6 focus sites).

Personnel

- Senior Researcher: Tony Rodriguez
- Graduate student: (1)
- Technician: (1)

Parameters/Variables

Spatial data (x, y, and z or easting, northing, and elevation) will be collected. For example, millions of data points will be collected from each of the six 600-meter wide focus sites along the barrier.

Field and Laboratory Procedures

Sampling Design and Collection. A Riegl LMSZ210ii 3D terrestrial laser scanner system will be used to collect x, y, and z data points (point clouds) at each site. The system is capable of mapping a 600 m-diameter circle at sub-centimeter resolution. Each point measured in this circle will have a footprint of about 1 mm. When the entire barrier is mapped, the laser scanner will be mounted on a 6-wheel drive Gator (borrowed from MCBCL).

Equipment Used. RTK GPS, Riegl LMSZ210ii 3D terrestrial laser scanner

Data Management

Raw and processed data will be integrated into the DCERP data and information management system. Units of measure will be eastings, northings, and meters. Data will not be sent directly to the repository from the monitoring equipment. Topographic maps and grid files will also be integrated into the Document Database.

6.3.4.5.6 Data Analysis, Products, and Outcomes

- Data will be gridded into three-dimensional perspective maps. Successive maps will be subtracted to calculate volume change and rate of change.
- Rate of change in habitat aerial extent is an important factor for the ecosystem model; particularly, when forecasting. Changes in barrier elevation indicate vulnerability to storm surge and sea-level rise. Changes in barrier volume indicate longshore transport and the balance between sediment supply and accommodation-space creation.

6.3.4.6 Sediment Compaction, Texture, and Composition

6.3.4.6.1 Objectives

The objective of monitoring sediment compaction, texture, and composition is to use these metrics as indicators of habitat quality. Sediment texture varies with the intensity of hydrodynamic processes, as the aerial extent of habitats change, and when dredge material is deposited on the barrier. Vehicles compact sediment, which degrades the habitat quality of benthic invertebrates. Variations in sediment composition helps determine transport pathways, given the extreme variability in the framework geology along Onslow Beach (Robertson, 1994; Filardi, 1999).

6.3.4.6.2 Relevance to the Base

A key management objective is to sustain sea turtle and shore bird use, which involves habitat quality as defined by sediment characteristics and dependant benthic invertebrate prey resources. Sediment

compaction, texture, and composition are important factors in sediment transport, benthic invertebrate composition and abundance, bird-foraging success, and thus habitat quality.

6.3.4.6.3 Scale

Samples will be obtained along 6 monitoring focus sites. Both terrestrial samples and sea-floor samples will be analyzed. Along-beach variability in sediment texture is likely lower than the spacing of the 6 monitoring swaths (Cleary and Riggs, 1999).

6.3.4.6.4 Linkages within the Module and among other Modules' Monitoring Components

Sediment texture is important for all of the module teams; however, it is likely to have higher temporal variation on the coastal barrier given the higher energy environment. Sediment compaction, texture, and type are important variables to consider when evaluating habitat quality and will be integrated into the bird, sea turtle and benthic invertebrate monitoring activities and used in Research Project CB-3.

6.3.4.6.5 Methods

Spatial/Site Locations

Figure 6-11 is not at an appropriate scale to show individual sampling site locations. Approximately 30 samples will be obtained from -10 m below sea level to the interface between the dune and marsh (evenly distributed). Sampling will take place semiannually from the 6 focus sites, 2 of which experience off-road driving, 2 amphibious landings, and 2 with limited human disturbances.

Temporal Considerations

Samples and measurements of compaction, sediment texture, and composition will be collected twice a year: once in May and once in September.

Personnel

- Senior Researcher: Tony Rodriguez
- Graduate student: (1) (the same graduate student used in Section 6.3.4.5)
- Technician: **(**1)

Parameters/Variables

Grain size will be measured in individual weight percent and broken into 100 bins from greater than 2000 microns (gravel) to 0.04 microns (clay). Sample mineralogy including % carbonate, % lithic, and % mineral will be quantified on 1/4 of the samples. Adjacent to each sample location, compaction (stress or Pa) will be measured in-situ.

Field and Laboratory Procedures

Sampling Design and Collection. Samples will be obtained using a piston coring device from the shoaling zone to 10 m below sea level and 7.5 cm-diameter shallow sediment cores elsewhere. The number of samples (20) that will be taken along each focus site were chosen to capture the spatial variability in grain size and composition that commonly exists between the dune, foreshore, upper shoreface, and lower shoreface. Sample mineralogic composition will be determined using a binocular microscope. A cone penetrometer will be used to measure compaction.

Equipment Used.

- Cilas 1180 Laser Particle Size Analyzer
- Piston corer

- Hand corer
- Cone penetrometer
- Binocular microscope
- 2000 micron sieve

Data Management

Raw data will be integrated into the DCERP data and information management system. Units of measure will be individual weight percent and cumulative weight percent for 100 different size classes from gravel (> 2 mm) to clay (< 0.0039 mm), percent shell, lithic, and mineral for the sediment samples, and stress where penetrometer readings will be obtained.

6.3.4.6.6 Data Analysis, Products, and Outcomes

Graphs of individual weight percent versus diameter will be produced for each sample. The diameters at 10%, 50%, 90%, and the mean will be calculated. Maps of mean grain size, compaction, and mineralogy will be produced and integrated with monitoring of benthic invertebrates, shore birds, and sea turtles. Sediment texture, mineralogy, and compaction indicate habitat quality and extent. For example, foraging success, turtle-nesting site locations, and sediment transport are all controlled, in part, by sediment texture.

6.3.4.7 Benthic Invertebrates

6.3.4.7.1 Objective(s)

The sandy-beach macroinvertebrates will be monitored along the ocean beaches (and on sand flats on inlet and back barrier shores for the shorebird productivity Research Project CB-3 in Years 2 and 3) because these animals represent the universal food supply for all demersal surf fishes and shorebirds, a prey resource that is impacted by natural physical-sedimentological forcing mechanisms and by Base activities (physical disturbance by vehicles and more importantly, by massive sediment deposition and potential changes in sediment character during and after potential beach nourishment).

6.3.4.7.2 Relevance to the Base

Efforts will ensure that MCBCL supports all required military training activities while complying with the ESA and other wildlife requirements. Data and associated analyses will be used to develop conservation management procedures and to best design mitigation in the case of beach nourishment or the introduction of new uses to the coastal barrier system.

6.3.4.7.3 Scale

Benthic invertebrates vary spatially along ocean beaches if there are differences in sedimentology, sediment transport rates, or predation intensity. In addition, the benthos of the beach changes with elevation from the shallow subtidal (−1 m depth at low tide) to the higher intertidal, requiring that sampling be done along vertical transects. Temporally, the benthic invertebrates of North Carolina beaches have an intense seasonal cycle related to reproductive pulses in spring and summer, mortality by predation during summer and fall as the surf zone serves as nursery for pompano, sea mullet, and flounders, and as shorebird predation is intense, especially during migration. Maximum abundances and biomass occurs around May and minimum around January. Thus sampling is best done on multiple dates to capture an indication of peak abundance in spring and abundance in fall when shorebirds and surf fish still require prey from this habitat. Intense storms may also induce some temporal dynamics, thought to reflect transport and passive migration offshore with subsequent return to the intertidal zone as conditions calm and sediment is gradually welded back onto the beach face. Thus, event-scale sampling is important relative to hurricanes.

One beach invertebrate, the ghost crab, is an important predator on sea turtle eggs and perhaps also hatchlings. It constructs burrows from the mid intertidal zone to the back dunes, requiring sampling by vertical transects perpendicular to the shoreline and extending back to where the burrows disappear. On sand flats where the physical energy levels are dramatically reduced, there is also a seasonal cycle in abundance, driven more by reproductive periodicity, growth of the invertebrates, and predation pressure. Thus sampling of invertebrates on these protected sand flats as part of the shorebird feeding study will be conducted concurrent with feeding observations.

6.3.4.7.4 Linkages within the Module and among other Modules' Monitoring Components

The monitoring of benthic macroinvertebrates on the ocean beaches will be matched in time and space to all the linked measurements of process and state of other relevant physical and biological variables so as to allow construction of the process-based understanding of coastal barrier ecosystem dynamics. Specifically, the wave and longshore current information will be continuous. The geomorphology, sediment transport, and sediment composition monitoring will be done semiannually and on an event scale before and after major storms, and conducted on the identical 6 sites as will be monitored for the ocean beach benthic invertebrates. The barrier vegetation will be monitored on those same six sites quarterly, including each of the May and September dates when benthos is to be sampled. The shorebird habitat use monitoring is done along the entire barrier and recorded by mile from inlet to inlet about every 10 days during the productive season by Base personnel. Thus these observations, which are species-specific, can and will be binned to extract numbers matching each of our six sites. Sea turtle nesting and false crawls are recorded site-by-site along the entire barrier for every day in the nesting season and hatching success recorded at the end of the season, so these data too can be readily binned to match the six study sites. Consequently, the entire set of interacting ecosystem processes is matched in time and space to allow analysis, synthesis, and interpretation of how the coastal barrier ecosystem is organized and how these processes interplay to dictate shoreline position, island area, and success of listed and other species of concern.

The other ecosystem components that are directly tied to the benthic invertebrates are the wave energy and sediment transport, the sediment composition, and the shorebird feeding and nesting success. On the event scale of major storms (hurricanes and northeasters), we will assess by before-after sampling how the benthic invertebrate resources are affected by and how they recover from the intense physical disturbance of waves and sediment transport. By linking these two aspects of the ocean beach system, we will test the null hypothesis that the benthic macrofauna of the sandy beach is simply transported offshore along with sediments during storms as a dissipative beach is formed and then transported back into the intertidal (especially swash) zone as calm conditions restore a more reflective beach condition by welding sands from offshore bars back onto the intertidal beach face. Testing this hypothesis relating to adaptation of the benthos to dynamic sediment movement has significant application to avoiding or minimizing habitat impacts associated with potentially desirable beach nourishment because the Environmental Impact Statement (EIS) or Environmental Assessment (EA) prepared in support of beach nourishment can then be based on site-specific field evidence of the resilience of the benthos to massive sediment transport.

In addition, assessing how the benthos varies with sediment grain size and shell content through analyzing the associations of sedimentology with benthic invertebrates will provide insight into how the legacy of high-energy sediment transport in the form of sedimentology has a lasting impact on the benthos. This information too has great practical significance because this too is critical in a EIS or EA in support of potential beach nourishment in situations like Onslow Beach where beach-compatible sand resources are difficult to locate nearby. By relating sedimentology to benthos, we will test the hypotheses that coquina clams are suppressed by coarse sediments, including shell hash, whereas mole crabs are facilitated by coarse sediments. Then by assessing how shorebird feeding and nesting success are related

to the abundance and biomass of major benthic taxa (coquina clams, mole crabs, amphipods, and polychaetes), we will collect the necessary site-specific information on how natural changes in sedimentology or modifications of sediment size through potential beach nourishment to predict the impact of the ocean beach as habitat for shorebirds and, by extension surf fishes. We will test the specific hypotheses that because willets target large mole crabs they are enhanced by how coarsening of sediments promotes mole crabs, that because sanderlings consume only small coquina clams, mole crabs of all sizes, amphipods, and polychaetes that their response to sediment size change must depend on the entire benthic community, and because ruddy turnstones and plovers utilize drift (stranded invertebrates along drift lines) and drift is composed mostly of mole crabs, that sediment coarsening will favor these shorebirds. This too has importance for EIS and EA development in support of beach nourishment because the piping plover is a listed species of federal concern.

Finally, we will relate the habitat choice of red knots, a migratory shorebird species of concern likely soon to be listed, to sedimentology and prey resources. For those species like the red knot and plovers that forage intensively on sand flats on the back-barrier shores, we have a specific Research Project CB-3 involving experimental testing of how habitat choice, feeding success, and nesting success (productivity) depend on history of overwash, current sedimentology, and the likely dependent macrobenthic prey community in a research project that is made ecosystem-based by linking sediment transport during storms, sedimentological legacies, macrobenthos prey, and shorebirds.

6.3.4.7.5 Methods

Spatial/Site Locations

Six focus sites (see **Figure 6-11**) are distributed along the extent of the Onslow Beach coastal barrier so as to locate two in the southern zone, where recreational driving is the major potential stressor, two in the central zone, where amphibious landing activities are the major potential stressor, and two in the northern zone, where human disturbance is minimal. At each of these sites, not only will data on the benthic invertebrate resources be collected, but also on every other ecosystem aspect (waves, ocean currents, nearshore bathymetry, nearshore structural geology, sedimentology, shoreline position, island geomorphology, vegetation cover, height, and diversity). As part of the DCERP Baseline Monitoring Plan, we will also integrate data routinely collected by the Base on shorebird use by species (every 10 days) and locations of nests, false crawls (daily), and nesting success (annually) of sea turtles to complete our ability to synthesize the coastal barrier ecosystem and test and model its dynamics in response to both natural and human-induced disturbances.

The macrobenthic sampling strategy involves sampling along two replicate vertical transects at each of the 6 focus sites. Vertical transects allow samples to be stratified by elevation, which explains a large fraction of the variance in benthos on the beach because of sharp environmental gradients. Each vertical transect will cover three elevation zones: the shallow subtidal (0–1 m depth); the swash zone, and the intertidal zone from the top of the swash (the highest extent of the wave) to where the beach sands stop remaining wet throughout the low tide. Sampling will be done in each case at low tide so as to render conditions identical at each site. Three replicate core samples will be extracted in random positions within each elevation zone. Along each transect, a different method will be used to sample ghost crab abundance. From the low intertidal to where burrows end in the dunes, ghost crabs will be counted by counting numbers of active (tracks present) burrow openings (a tested method from previous studies: Peterson et al., 2006).

Temporal Considerations

Sampling to monitor the benthic invertebrates of the ocean beach will be done twice annually, in spring (May) and fall (Sept). This frequency does not permit estimation of total seasonal production, which requires bimonthly or even monthly sampling. However, May is the month of peak abundance of coquina

clams on nearby Bogue Banks and September is often the time of peak abundance for mole crabs, so these two dates allow some inference on annual production. In addition, and most importantly, these dates coincide with monitoring of sediments, geomorphology, and vegetation, while waves, currents, shorebirds, and sea turtle nests are continuously monitored, allowing the ecosystem integration. Sampling of benthic invertebrates on the ocean beach will also be done before and after at least two major storms (likely hurricanes) during the 4 years. The sampling after storms will be immediate and then weekly until recovery has occurred or evidently will not occur.

Personnel

- Senior Researcher: Pete Peterson
- Post-doctoral Student: (1)
- Graduate Student: Beth VanDusen

Parameters/Variables

- Variables to be measured for the benthic invertebrates of the ocean beach habitat at each of the 6 monitoring sites are abundance per running meter of shoreline and density per square meter of shallow subtidal to intertidal beach by dominant taxon (coquina clams; mole crabs; amphipods; and polychaetes). For coquina clams and mole crabs, size frequencies will also be measured because many shorebirds are restricted to preying on certain sizes of benthic invertebrates. In addition, the abundance of ghost crabs will be estimated from counts of active burrows and also scaled per running meter of shoreline.

Field and Laboratory Procedures

Sampling Design and Collection. Methods for sampling coquina clams, mole crabs, amphipods, and polychaetes in 3 elevation zones from -1 m depth to the top of the intertidal wetted zone of the beach will follow well-established methods (Peterson et al., 2000; 2006). Cores of 82-cm^2 in surface area will be taken to 15 cm depth with an aluminum hand corer (a “clam gun”). Each sample will be a composite of 3 cores, each taken at random within the elevation stratum. Core contents will be sieved through 1-mm mesh in the field and animals transferred into plastic jars preserved in 10% formalin and seawater. These jars will be labeled with date, site, transect within site, and elevation stratum and kept in the UNC-IMS lab until the animals can be sorted, identified, and counted by major taxon. Mole crabs and coquina clams will be separated into 5 size classes by using nested meshes in the lab to provide size-frequency information. The ghost crab abundance on each transect will be estimated by counting all active burrows within a 1-m wide swath from the low intertidal to the shoreward termination of their distribution. This process is known to provide a good index of abundance (Wolcott, 1978). On each transect, both those used to measure abundance of benthic invertebrates by coring and those used to estimate ghost crab abundance, we will measure the linear extent of each elevation zone (coring) and the entire transect (ghost crab burrow counting). That measurement permits computation of density per unit area and also provides an indication of the extent of each relevant beach habitat (Peterson et al., 2006).

Equipment Used.

- Wild M2 binocular microscopes (3)
- Wooden floatable sieves (4)
- Aluminum sampling corers (4)
- Nested series of 4 laboratory sieves

Data Management

Location of sample, type of sample, date of sample collection, taxonomy and abundance data will be organized in a spreadsheet and integrated into the DCERP data and information management system.

6.3.4.7.6 Data Analysis, Products, and Outcomes

Benthic macrofaunal data from the sampling will be reduced to two measures for sampling of each site: (1) the mean density by taxon per square meter (+ standard error [SE]) averaged over the 3 elevation strata; and (2) the estimated abundance by taxon per running meter of shoreline (+SE), computed by a weighted average of the mean density in each elevation stratum times the width of the stratum. For the ghost crabs, the counts along the 2 transects will be averaged (+SE) for each site and date. These data will be synthesized with information on densities of feeding shorebirds, nesting site selection by sea turtles and nesting success, sediment size distribution, physical energetics (waves and sediment transport), beach geomorphology (shoreline position and topography, especially of the dune fields behind the shoreface), and vegetation cover and height to test via multiple regression analysis several hypotheses of relevance to management on the Base.

The data on benthic invertebrate abundance and density will each be combined with information on other components of the coastal barrier ecosystem to test a series of ecosystem-based hypotheses to inform management of Base activities. The other ecosystem components that are directly tied to the benthic invertebrates are the wave energy and sediment transport, the sediment composition, and the shorebird feeding and nesting success. On the event scale of major storms (hurricanes and northeasters), we will assess by before-after sampling how the benthic invertebrate resources are affected by and how they recover from the intense physical disturbance of waves and sediment transport. By linking these two aspects of the ocean beach system, we will test the null hypothesis that the benthic macrofauna of the sandy beach is simply transported offshore along with sediments during storms as a dissipative beach is formed and then transported back into the intertidal (especially swash) zone as calm conditions restore a more reflective beach condition by welding sands from offshore bars back onto the intertidal beach face.

In addition, assessing how the benthos varies with sediment grain size and shell content through analyzing the associations of sedimentology with benthic invertebrates will provide insight into how the legacy of high-energy sediment transport in the form of sedimentology has a lasting impact on the benthos. This information too has great practical significance because this too is critical in a EIS or EA in support of potential beach nourishment in situations like Onslow Beach where beach-compatible sand resources are difficult to locate nearby. By relating sedimentology to benthos, we will test the hypotheses that coquina clams are suppressed by coarse sediments, including shell hash, whereas mole crabs are facilitated by coarse sediments. Then by assessing how shorebird feeding and nesting success are related to the abundance and biomass of major benthic taxa (coquina clams, mole crabs, amphipods, and polychaetes), we will collect the necessary site-specific information on how natural changes in sedimentology or modifications of sediment size through potential beach nourishment to predict the impact of the ocean beach as habitat for shorebirds and surf fishes. We will test the specific hypotheses that because willets target large mole crabs they are enhanced by how coarsening of sediments promotes mole crabs, that because sanderlings consume only small coquina clams, mole crabs of all sizes, amphipods, and polychaetes that their response to sediment size change must depend on the entire benthic community, and because ruddy turnstones and plovers utilize drift (stranded invertebrates along drift lines) and drift is composed mostly of mole crabs, that sediment coarsening will favor these shorebirds. This too has importance for EIS and EA development in support of beach nourishment because the piping plover is a listed species of federal concern. Finally, we will relate the habitat choice of red knots, a migratory shorebird species of concern likely soon to be listed, to sedimentology and prey resources. For those species like the red knot and plovers that forage intensively on sand flats on the back-barrier shores, we have a specific research project involving experimental testing of how habitat choice, feeding success, and nesting success (productivity) depend on history of overwash, current sedimentology, and the likely dependent macrobenthic prey community in a research project that is made ecosystem-based by linking sediment transport during storms, sedimentological legacies, macrobenthos prey, and shorebirds.

We anticipate development of a reliable index of habitat value for foraging shorebirds and surf fishes that is based upon the biomass of key taxa of benthic macroinvertebrates because these organisms represent the prey for both groups of valued predatory vertebrates. Until we complete an analysis of which combinations of benthic taxa best explain shorebird foraging patterns, the precise nature of that index will remain unspecified. To test alternative indices based on benthic data, we will use information criteria to determine which combination of prey data provides the best fit to bird foraging numbers. These analyses will include covariates of season (May versus September) and mean grain size of sediments to factor out contributions from other sources of variation. Traditionally, benthic macrofauna has provided the most reliable and widespread indices of ecosystem health and function. For the ocean beach, the logical basis for development of such an index is compelling because the benthos forms the prey for the surf fish and shorebirds. This new index has significant application to avoiding or minimizing habitat impacts associated with potentially desirable beach nourishment because the EIS or EA prepared in support of beach nourishment can then be based on site-specific field evidence of the resilience of the benthos to massive sediment deposition.

6.3.4.8 Surf Fish and Sea Turtles

6.3.4.8.1 Objectives

The main objective of monitoring surf fishes at each of the 6 focus sites once each year is the quantification of the habitat value of the ocean beach as foraging grounds for recreationally and commercially important surf fishes, notably pompano, Gulf kingfish, red drum, spot, and flounders. These demersal surf fishes prey upon benthic macroinvertebrates and along with shorebirds contribute to inducing seasonal changes in abundance of the benthos and to patterns of abundance relative to natural and human disturbances.

Loggerhead and other sea turtles that nest on North Carolina beaches are listed species covered under the ESA. The Base monitors daily and plots the location of each successful nesting attempt and each false crawl along the entire beach of Onslow Beach over the nesting season. In addition, any nest judged to be at risk to military activities is moved to safer grounds. The hatching success of all eggs in every nest is recorded when the turtles emerge. We will use the Base monitoring data to provide insight into how sea turtle nesting site choice and hatching success vary with natural conditions and Base activities.

6.3.4.8.2 Relevance to the Base

Monitoring efforts will ensure that MCBCL supports all required military training activities while complying with the ESA and other wildlife requirements.

All Atlantic sea turtles are federally listed and under the ESA require assessment of how Base activities affect their population recovery. The obligations of the Base under the ESA will be best fulfilled by testing how natural versus Base activity-induced perturbations affect the status of these species and assessing how targeted management actions could enhance recovery. Monitoring of the coastal barrier ecosystem and the physical/sedimentological/geomorphological aspects of the system will allow tests of hypotheses explaining the observed variation in success of these and other wildlife species. Specifically, we will test whether recreational beach driving, amphibious landings, presence of or restoration of a continuous dune line, and/or the potential disturbance of beach nourishment affects (1) nesting site choice of (loggerhead) sea turtles and their hatching success. Monitoring of surf fishes will be done on one occasion annually in September so as to quantify how surf fish abundance and composition varies among the three different management areas, that open to recreational driving, that used for amphibious training, and the one that is least disturbed. This will provide a test of whether surf fish abundance and community composition differ among beaches experiencing different levels of disturbance. Because the disturbance intensity on Onslow Beach is confounded with what may be natural differences among zones, our ecosystem-based study will include the ability to determine whether any observed differences in surf

fishes can be most parsimoniously explained by natural differences among zones in benthic invertebrate prey availability for surf fishes.

6.3.4.8.3 Scale

Seining to estimate end-of-season abundances and community composition of surf fishes will be conducted using replicate 30-m-long seine hauls at each of the 6 study sites. The most important surf fishes use the shallow subtidal and intertidal surf zone as a nursery habitat for foraging and predator protection, recruiting during colder months and then growing rapidly throughout the summer. A single sampling in early fall (September) provides a reasonable indication of annual production for Florida pompano, Gulf kingfish, and summer flounder, the fishes most dependent on surf zone habitat. Surf fishes move unimpeded along the beach, but one, the Florida pompano, does not move laterally along the beach more than about 50 m during (Ross and Lancaster, 2002). The other more mobile surf fishes are likely to become concentrated in areas where prey resources are most abundant, so that the spatial scale of distance between sites in our study design is appropriate for detecting differential use of the three zones along Onslow Beach for demersal surf fishes most closely tied to this habitat.

Sea turtle nesting and false crawls are recorded daily during the entire egg-laying season by Base personnel by specific location along the ocean and inlet shoreline of Onslow Beach. Thus, this temporal scale is suitable for determining the complete numbers of sea turtle nests and % of false crawls annually. Successful egg laying occurs based on spatial scales of individual female sea turtle perception when emerging from the ocean because what may interfere with egg laying is presence of an erosion scarp inhibiting ascension to the base of the dunes, geological characteristics of the beach soils, which can cause females to reject a site, and hardness and other factors affecting the digging capability of nesting sea turtles. Then survival of eggs depends on avoiding becoming washed away during storms, avoiding drowning, avoiding predation by ghost crabs, raccoons, and other predators, and avoiding other physical disturbance such as vehicular. The Base has management practices in place to promote the survival of sea turtles. Recreational driving is restricted from the recreational zone of Onslow Beach during the sea turtle nesting season (April 1 – August 31). In addition, Base personnel move nests from training areas to protected areas of the beach and install anti-predation mesh around the nests. Since the spatial scale relates to the size of the female turtle and the hatching success of eggs once laid varies on the scale of the individual nest, using the Base monitoring of every nest until hatching provides data on appropriate spatial scales for testing impacts.

6.3.4.8.4 Linkages within the Module and among other Modules' Monitoring Components

Surf fish abundance by site (and thus by use zone along Onslow Beach) will be linked to the abundance, density, and biomass of benthic macroinvertebrates, which are the prey for these demersal (bottom-feeding) fishes. Mole crabs and coquina clams are the most important of the benthic macroinvertebrates in diets of surf fishes, although amphipods also play an important role for small juveniles early in the spring season. Surf fish also respond directly to sedimentary habitat. Flounders chose sand and typically reject shell bottoms. Pompano ingest shell fragments, mistaking it for living mollusks, which reduces their predation rate on coquina clams (Manning, 2003). Pompano also avoid shelly areas probably because of their reduced feeding efficiency. Consequently, we will interpret fish abundance among use zones by reference to sedimentology and prey abundance to enable us to test whether disturbance regime influences surf fish abundance. Because the demersal surf fishes consume the same prey as shorebirds, we will also use our estimates of surf fish abundance, adjusted for sampling efficiency of beach seining, to estimate by standard fish bioenergetics their predation pressure on benthic invertebrates and compare that to the predation pressure applied by shorebirds to interpret seasonal dynamics and spatial pattern in the benthic macrofauna.

Sea turtle nesting choices (successful egg laying versus false crawls) will be linked to our data on shoreline geomorphology (especially presence/absence and height of erosion scarps and foredunes) and beach sedimentology (grain size, beach hardness via penetrometer readings, shell hash and fragment content) as a means of testing whether these variables influence the success of egg-laying. Hatching success of sea turtles will be linked with data on sedimentology at the nesting location, storm and beach erosion information from the physics and abundance of ghost crabs.

6.3.4.8.5 Methods

Spatial/Site Locations

Monitoring sites for surf fishes are the same set of 6 focus sites (**Figure 6-11**) used to measure other aspects of the barrier island ecosystem. Our map of the spatial locations of the 6 sampling sites for monitoring the coastal barrier ecosystem, including the surf fishes, is on a scale too coarse to illustrate the complete spatial pattern and strategy of sampling. We have identified 6 monitoring sites distributed along the extent of the Onslow Beach coastal barrier so as to locate 2 in the southern zone, where recreational driving is the major potential disturbance, 2 in the central zone, where amphibious landing activities are the major potential disturbance, and 2 in the northern zone, where human disturbance is minimal. Sea turtle data are taken continuously along the entirety of Onslow Beach and we will bin those into equal stretches of ocean shoreline corresponding to each of our 6 study sites.

Temporal Considerations

Monitoring for surf fish will occur once annually during September. Monitoring nesting of sea turtles is done daily by MCBCL and egg hatching success is done such that integrated counts are produced over the entire season for every nest.

Personnel

- Senior Researcher: Pete Peterson
- Graduate Student: Beth VanDusen

Parameters/Variables

- Abundance of surf fishes by species at the end of the nursery season
- Numbers of sea turtle nests constructed and % of nesting attempts that are successful versus numbers of false crawls
- % of nests yielding hatchlings and % of eggs hatching per nest

Field and Laboratory Procedures

Sampling Design and Collection. At each focus site, we will not only collect data on surf fish abundance and community composition, but also on every other ecosystem aspect (waves, ocean currents, nearshore bathymetry, nearshore structural geology, sedimentology, shoreline position, island geomorphology, vegetation cover, height, and diversity). Replicate (n=2) beach seining at low tide under calm sea conditions once annually in Sept will be used to estimate surf fish abundance and community composition as a function of Base activities, invertebrate prey abundance, and sedimentology (especially shell content). Replicate seine hauls will be positioned with 80 m separation between them as subsamples for each site.

For sampling surf fish, we will use a beach seine 6 m wide with 1 inch mesh and a tail bag, attached to smooth poles at each end to facilitate seining. Hauls will be done under calm conditions at low tide, holding time of day constant (early morning). Two replicate hauls will be made at each of the six sites, with hauls covering 40 m and spaced 80 m apart. Two crews will work simultaneously so as to complete

sampling on a single early morning. All fish captured will be identified in the field and counted by species before returning them alive to the sea.

Sea turtle nesting attempts and success/failure are determined daily through observations of tracks and digging disturbance by early morning drives along the entirety of the ocean and inlet beaches of Onslow Beach. Nests are marked, both those to remain and those that are moved, such that complete excavation after hatchlings have emerged can provide evidence of the % of eggs successfully hatched.

Equipment Used.

- Beach seine
- 4-wheel drive truck with GPS

Data Management

Location of sample, type of sample, date of sample collection, taxonomy and abundance data, as well as location, date and success of each sea turtle nesting attempt and egg hatching rate of each nest by location will be organized in a spreadsheet and integrated annually into the DCERP data and information management system.

6.3.4.8.6 Data Analysis, Products, and Outcomes

The data on abundances of surf fishes will be compiled as means (+SE) of each species per site (1–6) and means per beach zone (n=3) each year. This information will be analyzed in multiple regressions and analysis of covariance (ANCOVAs) to determine if surf fish abundance in total and by species varies with disturbance level along the beach (recreational driving zone versus amphibious training zone versus low disturbance), while using covariates of abundance of benthic invertebrate prey, and mean grain size and shell content of sediments to factor out variation attributable to natural ecosystem drivers. In addition, estimates will be made from standard fish energetics of the food consumption rate of invertebrate prey by surf fishes such that this can be combined with analogous estimates for shorebirds to test the hypothesis that the seasonal declines in abundance of benthos from May to September can be explained by predation. This comparison of surf fishes to shorebirds also serves to test the hypothesis that competition with surf fishes helps reduce prey for shorebirds and thus may affect their ability to feed nestlings and newly fledged young, thereby reducing breeding success. This understanding of the roll of surf fishes will be used in Research Project CB-3 to explain variations in nesting success of key shorebirds.

The data on sea turtles nesting and reproductive success will be used to test several hypotheses relative to natural and human-driven forcing. We will assess whether site selection for egg laying and hatching success varies significantly with the presence of erosion scarps, foredunes of various elevations, sediment grain size, shell content of sediments, and sediment hardness in a multiple regression analysis. This analysis provides insight into how to design potential beach nourishment in ways that will avoid impacts on sea turtle reproduction on Onslow Beach. The analysis also helps inform the Base on how well they are selecting locations for transferring sea turtle nests laid in at-risk areas. Finally, we will conduct ANCOVAs on the egg laying success data and hatching success data as dependent variables in separate analyses and with natural drivers of nest selection as co-variates (presence of erosion scarps, sediment grain size, shell content of sediments, and sediment hardness) to evaluate whether human disturbance influences these two components of reproductive success by comparing the recreational, amphibious training, and low-disturbance zones.

6.3.4.9 Shorebirds and Seabirds

6.3.4.9.1 Objective(s)

In the context of the Coastal Barrier Module's conceptual model, the purpose of monitoring shorebirds and seabirds is to use the responses (e.g., habitat use for feeding, survival, reproduction, and abundance) of these mid-trophic level vertebrates as indicators to the ecosystem impacts of anthropogenic and random forces in MCBCL's coastal barrier system. Shorebirds and seabirds will respond to alterations in both benthic prey and the balance of predators, and so monitoring these taxa in the long-term will serve as an indicator of overall barrier island ecosystem integrity. In the context of key management objectives, intense monitoring during the next 4-year period by MCBCL, historical analyses of MCBCL's avian monitoring data by this team, and concurrent research on shorebirds and predators by this team will result in a scientifically-tested protocol for monitoring the impacts of future Base and non-Base related changes. These activities will increase the long-term management capacity for natural resource assets of MCBCL's coastal barrier system

6.3.4.9.2 Relevance to the Base

Monitoring will ensure that MCBCL supports all required military training activities while complying with the ESA and other wildlife requirements.

Analyses of MCBCL's 6-year dataset on shorebirds and seabirds in concert with productivity and survival research studies of important avian species will allow the design of a simplified, more efficient monitoring protocol for shorebirds and seabirds to be implemented by MCBCL. Instead of sampling all shorebirds, MCBCL may best use limited resources for environmental studies by sampling key species such as piping plovers (Federally Threatened), Wilson's plovers (a proxy for piping plovers, species of High Concern), red knots (Federal Candidate for ESA listing), and/or least terns (species of concern). Instead of repeated surveys every 7–10 days across the year by MCBCL, we may be able to limit their monitoring to a few key weeks per year depending on the outcome of these analyses. We might also redirect the spatial extent of the monitoring activities to be more resource efficient (time and monetary resources). Information and refined procedures obtained during this study will be incorporated into the Base's INRMP to best meet the intent of the ESA and MOU with the USFWS. Historical, present-day, and future monitoring data will be used to best design mitigation in the case of beach renourishment or the introduction of new uses to the coastal barrier system. This can be done through understanding how sediment characteristics (grain size and shell content) influence foraging by shorebirds. Grain size and shell content represent two aspects of sand resources for beach nourishment that can be affected by source site for the project.

6.3.4.9.3 Scale

First, we will analyze relevant historical data collected by MCBCL on MCBCL's coastal barrier properties. Second, while we are conducting these historical analyses and concurrent shorebird productivity and survival research in the region spanning North Topsail Beach to Brown's Inlet, MCBCL will continue their monitoring program only on Base beaches. These ongoing shorebird monitoring results are done continuously along the entire ocean and inlet shore of Onslow Beach, such that we will be able to bin them by site to include in analyses of ecosystem state and inter-relationships with natural and human-induced forcing.

6.3.4.9.4 Linkages within the Module and among other Modules' Monitoring Components

Analyses of shorebird and seabird historical monitoring data will consider data collected along the entire accessible barrier island system at MCBCL (see **Figure 6-11),** so it will overlap with all other Coastal Barrier monitoring activities. This will allow trends in avian populations to be related to other barrier

island monitoring trends such as historical changes in overwash frequency, spatial locations of historical overwash, shoreline bathymetry, and shoreline sediment structure.

6.3.4.9.5 Methods

Spatial/Site Locations

Because the distribution and nest-site selection of avian species cannot be predicted down to an exact location between years, MCBCL monitors the barrier island ocean beaches from the New River inlet to the impact zone in the north (see **Figure 6-11**). Habitats monitored by MCBCL include ocean beach, overwash areas, and inter-tidal areas adjacent to inlets. The concurrent Research Project CB-3 will expand avian studies to include more intertidal areas adjacent to and behind the barrier islands and our ultimate recommendations to MCBCL may be to limit their monitoring temporally, but increase it spatially

Temporal Considerations

First, as part of this DCERP Baseline Monitoring Plan, we will be conducting analyses on a 6-year historical dataset. Data will be subset to focus on key species of concern and key time series of concern that will be determined based on the findings of other monitoring projects. For example, we will look at shorebird/seabird abundance by beach sections of different sediment structure or shoreline bathymetry. We also will explore trends in avian abundance and community structure in before and after historical overwash or major storm events.

Additionally, we will conduct a sample of concurrent monitoring surveys with MCBCL to determine if MCBCL are missing key species or significant numbers of individuals by focusing almost completely on ocean beaches. We will use different methods (e.g., foot surveys versus MCBCL vehicle surveys, point counts versus transects) and survey different habitats (e.g., back-beach, intertidal flats behind the island) to determine how to modify MCBCL spatially and temporally to most efficiently use resources.

Concurrent with these monitoring activities, we will be conducting a Research Project CB-3 to quantify avian productivity and survival on MCBCL barrier islands. We will relate abundance data collected by MCBCL monitoring staff during the project period to observed avian population parameters. We will conduct concurrent studies to determine the benefits of using productivity and/or survival monitoring during key times of year versus year-round abundance surveys as the monitoring parameters.

Finally, we will use the ongoing shorebird monitoring conducted by the Base to provide information on intensity of shorebird foraging. Spatially we will bin these data to match our 6 sites. Temporally, these data are taken every 7–10 days, which provides us capacity to integrate foraging over long time scales to characterize the 3 beach zones well (recreation zone where off-road beach driving occurs, amphibious training zone, and low-use zone). These routine sampling will also coincide with our May and September samplings of all the major ecosystem components, including especially the benthic invertebrate prey, geomorphology, and sedimentology.

Personnel

- MCBCL staff that conduct avian monitoring on barrier islands (monthly August 2007 – July 2010)
- Senior Researchers: Sarah Karpanty and Jim Fraser
- Technician: 1 research technician

Parameters/Variables

First, we will analyze an appropriate subset of MCBCL historical monitoring data for trends in avian abundance by species and by beach zone. Data have been collected by species for 6 years by MCBCL

staff. Approximately every 7 to 10 days, Base staff conducts avian surveys in barrier ocean beach habitats and record abundance by species and beach mile marker. In our concurrent research activities, we will be collecting data on avian abundance, productivity and survival for key species (e.g., Wilson's plover, Red Knot, Least terns) that may be useful in designing a more efficient long-term monitoring strategy for MCBCL. Second, the ongoing shorebird monitoring done by the Base involves driving the entire ocean beach and inlet shore and counting all shorebirds by species for each mile segment of shore. This will represent our shorebird monitoring dataset to be integrated into the ecosystem analyses.

Field Procedures

Sampling Design and Collection. Field data has historically been collected and will continue to be collected by Base staff. This ongoing shorebird monitoring done by the Base involves driving the entire ocean beach and inlet shore and counting using binoculars all shorebirds by species for each mile segment of shore. We will also conduct several surveys concurrently with MCBCL to determine if the spatial extent, or temporal extent, of monitoring should be altered. Using historical data, we will conduct trend analyses for key species of concern (e.g., Red knots, Piping plovers, Wilson's plover, Least terns) from the 6 years of data collected by MCBCL staff. We will relate trends in avian abundance and spatial use of the ocean beach habitats to other monitoring variables, such as sediment texture, shoreline bathymetry, and overwash history.

Equipment Used. 4-wheel drive truck, 24-ft Carolina skiff, 2 spotting scopes, 2 binoculars, and drop traps.

Data Management

All field-data shorebird monitoring data will be entered into a digital format at the research station base. Raw and processed data will be integrated into the DCERP data and information management system via hard drive exchange.

6.3.4.9.6 Data Analysis, Products, and Outcomes

Data on bird abundance (from historical and ongoing monitoring analyses and concurrent avian research) and reproductive indices (concurrent avian research) will be used by ecosystem modelers to link the ecosystem components of the coastal barrier. Reproductive and abundance data will be analyzed using correlation/regression analyses and trend models by year and across-years to explore for trends and to relate any observed trends to other monitored variables in the coastal barrier module or other modules. Survival analyses will be conducted in Program MARK using an appropriate model, likely the Barker model. Reproductive success, survival and abundance of migratory and winter species can be used as indicators of health of these avian populations (**Table 6-9**).

Table 6-9. Proposed Shorebird and Seabird Indicators

Indicators	Condition			Comment/Source for the indicator and threshold values
	Healthy	Transitional	Poor	
Reproductive success				Targets will be determined in CB-3, combined levels of reproduction and survival that will lead to stationary or increasing populations.
Abundance of migratory/wintering species				Targets will be determined in CB-3, stationary or increasing numbers

The monitoring data on shorebird use will be combined with information on other components of the coastal barrier ecosystem to test a series of ecosystem-based hypotheses to inform management of Base

activities. The other ecosystem components that are directly tied to the shorebirds are the benthic invertebrate abundance and biomass and the sediment composition. On the event scale of major storms (hurricanes and northeasters), we will assess by before-after sampling how the shorebird habitat use is affected by and how they recover from the intense physical disturbance of waves and sediment transport. By linking these two aspects of the ocean beach system, we will test the null hypothesis that the shorebird use of the sandy beach is suppressed until the benthic invertebrate prey either migrate back to the intertidal beach or reproduce and recolonize. Testing this hypothesis relating to adaptation of the benthos and shorebirds to dynamic sediment movement has significant application to avoiding or minimizing habitat impacts associated with potentially desirable beach nourishment because the EIS or EA prepared in support of beach nourishment can then be based on site-specific field evidence of the resilience of the beach system to massive sediment transport. In addition, assessing how the shorebird use varies with sediment grain size and shell content through analyzing the associations of sedimentology with shorebird use will provide insight into how the legacy of high-energy sediment transport in the form of sedimentology has a lasting impact on the benthos. This information too has great practical significance because this too is critical in an EIS or EA in support of potential beach nourishment in situations like Onslow Beach where beach-compatible sand resources are difficult to locate nearby. By relating sedimentology to benthos, we will test the hypotheses that coquina clams are suppressed by coarse sediments, including shell hash, whereas mole crabs are facilitated by coarse sediments. Then by assessing how shorebird feeding and nesting success are related to the abundance and biomass of major benthic taxa (coquina clams, mole crabs, amphipods, and polychaetes), we will collect the necessary site-specific information on how natural changes in sedimentology or modifications of sediment size through potential beach nourishment to predict the impact of the ocean beach as habitat for shorebirds and surf fishes. We will test the specific hypotheses that because willets target large mole crabs they are enhanced by how coarsening of sediments promotes mole crabs, that because sanderlings consume only small coquina clams, mole crabs of all sizes, amphipods, and polychaetes that their response to sediment size change must depend on the entire benthic community, and because ruddy turnstones and plovers utilize drift (stranded invertebrates along drift lines) and drift is composed mostly of mole crabs, that sediment coarsening will favor these shorebirds. This too has importance for EIS and EA development in support of beach nourishment because the piping plover is a listed species of federal concern. Finally, we will relate the habitat choice of red knots, a migratory shorebird species of concern likely soon to be listed, to sedimentology and prey resources. For those species like the red knot and plovers that forage intensively on sand flats on the back-barrier shores, we have a specific research project involving experimental testing of how habitat choice, feeding success, and nesting success (productivity) depend on history of overwash, current sedimentology, and the likely dependent macrobenthic prey community in a research project that is made ecosystem-based by linking sediment transport during storms, sedimentological legacies, macrobenthos prey, and shorebirds.

We anticipate development of a reliable index of habitat value for foraging shorebirds and surf fishes that is based upon the biomass of key taxa of benthic macroinvertebrates because these organisms represent the prey for both groups of valued predatory vertebrates. Until we complete an analysis of which combinations of benthic taxa best explain shorebird foraging patterns, the precise nature of that index will remain unspecified. To test alternative indices based on benthic data, we will use information criteria to determine which combination of prey data provides the best fit to bird foraging numbers. These analyses will include covariates of season (May versus Sept) and mean grain size of sediments to factor out contributions from other sources of variation. Traditionally, benthic macrofauna has provided the most reliable and widespread indices of ecosystem health and function. For the ocean beach, the logical basis for development of such an index is compelling because the benthos forms the prey for the surf fish and shorebirds.

6.3.4.10 Dune, Shrub, and Marsh Plants

6.3.4.10.1 Objective(s)

The objective of monitoring is to understand short-term and long-term changes in vegetation in response to natural events such as storms and sea level rise, and anthropogenic effects, including military training and recreational use. This information will be used to develop a management plan that preserves the natural vegetation while sustaining Base training and recreation activities. In addition, vegetation monitoring on the coastal barrier has significance to the geomorphology of he barrier itself as vegetation traps sands and causes deposition of wind-blown particles, which helps elevate dunes and raise the elevation of the ground in shrub zones and in salt marshes. Vegetation information also relates to shorebird and tern nesting because these ground-nesting birds of the coastal barrier avoid areas with dense vegetation cover.

6.3.4.10.2 Relevance to the Base

The specific driver is to maintain MCBCL's barrier island system to provide maximum use for training activities while preserving its natural ecosystem functions and values. Preservation and maintenance of the native vegetation is a key component of the physical and biological processes of barrier islands. Vegetation contributes to sustaining the coastal barrier land mass in the face of major storms and sea-level rise through its role as a hydrodynamic baffle trapping sediments.

6.3.4.10.3 Scale

Vegetation on coastal barriers exhibits a strong pattern of zonation with distance from the sea in response to the stressor of salt spray. Consequently, our monitoring strategy employs transects that extend across the entire barrier from the base of the dunes through the salt marsh. In addition, elevation of the land plays an important role in determining the plant community present, so we will determine how elevation changes along transects. The 6 focus sites (see **Figure 6-11**) are widely spaced enough to make them essentially independent, so that spatial scale seems suitable for producing information to characterize how vegetation varies with land use on Onslow Beach.

6.3.4.10.4 Linkages within the Module and among other Modules' Monitoring Components

Monitoring of vegetation is closely linked to all the other ecosystem components within the Coastal Barrier Module because of the effects of vegetation on habitat for birds, mammals, invertebrate predators (ghost crabs), marsh invertebrates, and other fauna. Vegetation also affects physical processes such as sand accumulation to form dunes and sediment trapping by salt marsh, which ultimately affects island geomorphology. Vegetation cover plays an important role in dictating suitability for nesting by shorebirds, terns, and other ground-nesting birds of coastal barrier. Avian use of vegetated areas for roosting and nesting also leads to plant fertilization by guano deposition. Such processes induce more lush plant growth, covering more ground and extending taller because the low organic content and porosity of barrier island soils lead to nutrient limitation.

6.3.4.10.5 Methods

Spatial/Site Locations

Six fixed transects across the island perpendicular to the ocean shoreline will be established for sampling and monitoring. These represent 2 in the recreational zone where off-road beach driving occurs, 2 in the amphibious training zone, and 2 in the zone of limited human disturbances to the north (see **Figure 6-11**). Quadrants will be randomly placed in each plant community (stratum) along each transect to determine plant species composition cover, and height.

Temporal Considerations

Transect sampling will be conducted Years 3 and 4 in September or October, near the end of each growing season. Additional sampling will be done as needed to document effects of storm and intensive training events and the subsequent recovery or to follow the fate of dune or plant restorations done by the Base. Aerial photography, obtained each year by the base, will be use to measure plant cover within the dune, shrub, and marsh zones.

Personnel

- Senior Researchers: Pete Peterson and Tony Rodriguez
- Post-doctoral student: (1)

Parameters/Variables

- Cover (percent)
- Plant height (cm)
- Historic changes from available aerial photography
- Surface elevations as determined using laser scanner

Procedures

Sampling Design and Collection. Line transects will be established across the barrier island from the surf zone through the tidal marsh. Vegetation sampling will be stratified within each distinct vegetation zone that occurs across the island (which are organized by exposure to salt spray and elevation, scaling therefore largely with distance from the ocean). Quadrants will be randomly established by direction and distance from the line transects. Quadrant size will be adapted for each vegetation type. For example, one square meter quadrants are appropriate for herbaceous vegetation in the dune and marsh vegetation zones, whereas larger sampling plots will be needed for shrub and maritime forest vegetation.

The most current aerial photographs will be compared with photography from the past to determine changes in vegetation that may have occurred and relate those to overwash events, human disturbance, and restoration activities. Laser scanner data and our vegetation surveys on the ground will be compared over time to estimate the rates of elevation gained or lost (sand depositions or erosion) due to changes in vegetation cover and height. The effect of traffic on vegetation and sand stability will be evaluated to determine the need for active management of vegetation.

Equipment Used. PVC quadrants, Riegel LMSZ210ii 3D terrestrial laser scanner

6.3.4.10.6 Data Analysis, Products and Outcomes

The plant sampling data from quadrants will include average plant height, and percent cover. ANOVA will be used to determine if there are statistically significant differences in vegetation between the recreation, amphibious landing, and low impact areas as a function of vegetation zone. Products of vegetation monitoring will be vegetation maps, improved understanding of the impacts of and recovery from training and recreation on vegetation, the relationship of vegetation to island geomorphology and stability. These outcomes will provide a better management plan that will help sustain the training and recreation uses of the island while preserving the natural plant cover.

6.4 Terrestrial Module

6.4.1 Introduction

The terrestrial ecosystem refers to the gradient of vegetation from salt marsh at the estuary margin, through brackish/freshwater marsh, to the longleaf pine savannas and pocosins (shrub bog) that dominate

the terrestrial environments on MCBCL (Wells, 1942; Christensen, 2000). The gradients between these habitat types differentiate the terrestrial ecosystem of the coastal zone from that of inland sites, such as Fort Benning, where dry longleaf pine savannas and bottomland hardwoods dominate. Most of the rare species characteristic of coastal terrestrial ecosystems, including species of concern on MCBCL, are found in the transitional zones along these gradients.

Variation in the biota and ecosystem processes along these gradients is driven by variation in hydrology, soils, and fire behavior. **Figure 6-12** presents the conceptual model for the Terrestrial Module, illustrating the complementary nature of these critical physical, chemical, and biotic processes and interactions. Salt marsh ecosystems are inundated daily with saline waters, and freshwater/brackish marsh ecosystem soils are frequently saturated with waters of lower salinity. Pocosin vegetation occurs on poorly drained organic soils and experiences infrequent (> 40 years), high-intensity fires.[1] Longleaf pine savannas generally occur on shallow organic and mineral soils; the depth of the water table in these ecosystems varies from a few centimeters to more than a meter, depending on topography, creating a gradient between dry upland savannas and wet flatwoods. These variations have significant effects on plant composition and diversity (Walker and Peet, 1984). The locations of transitions from one ecosystem to another along this gradient are often influenced by disturbance (fire) history (Garren, 1943; Christensen, 1981). Specific conservation challenges associated with different parts of these gradients include recovering the endangered red-cockaded woodpecker (RCW) in longleaf pine savannas, promoting herb diversity (e.g., Venus flytrap, *Dionea muscipula*) in wet savanna-pocosin transitions, and combating invasive species in freshwater marshes. Fire is a natural part of this landscape, and natural fire regimes (frequency and intensity) change across this soil-hydrology-vegetation gradient, from frequent surface fires in longleaf pine savannas to relatively infrequent and intense crown fires in pocosins.

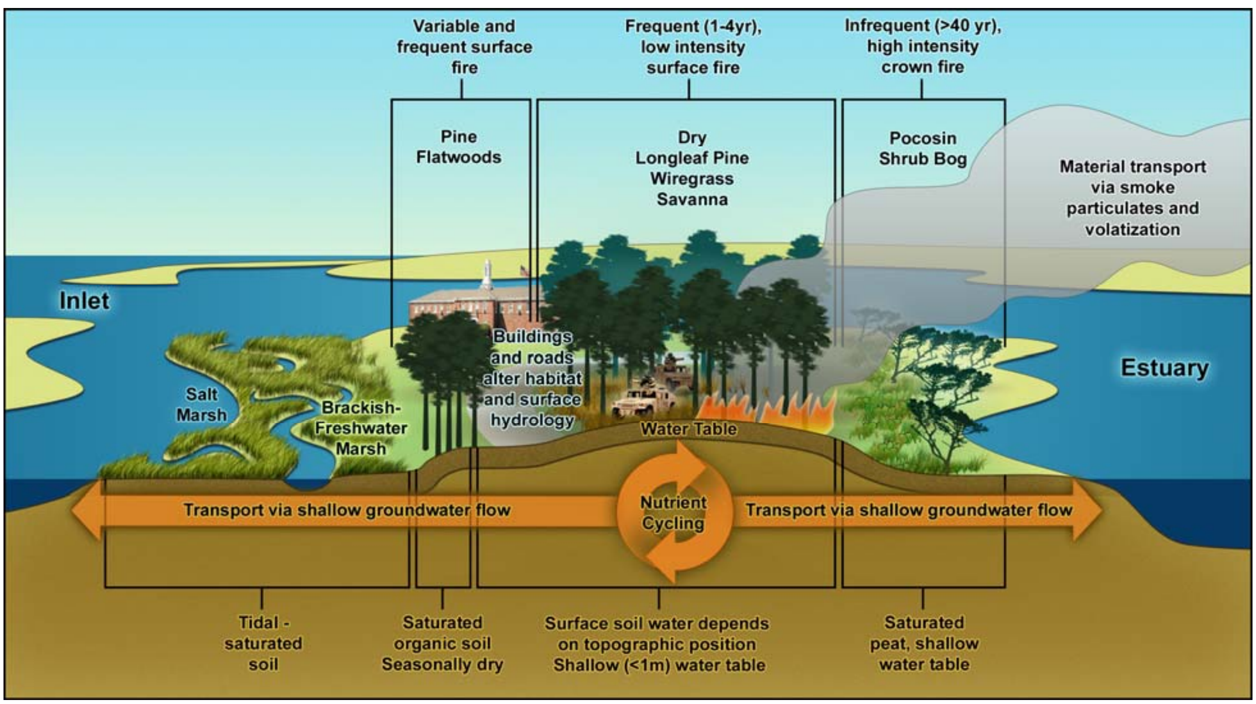


Figure 6-12. Conceptual model for the Terrestrial Module.

[1] This return interval is based on typical ages for pocosin pond pines which are killed to the root crown by fire. The historic range of variation for pocosin fire is unknown (Christensen et al.,1987).

The monitoring program for the Terrestrial Module focuses primarily on critical knowledge gaps related to two major issues in the Base's management of terrestrial habitats, use of prescribed fire and improvement of habitat for RCWs. Although the general relationship between fire and vegetation change is understood in longleaf pine forests and the utility of PB in managing such forests is well established, little is known about variations in natural fire regimes (i.e., frequency, season, and intensity of fire) along fuel and moisture gradients, and thus what changes in PB regimes might be appropriate across the soil-moisture gradient. This is particularly the case for pocosin and flatwood vegetation, and ecotones. The influence of such variations on total nutrient capital and patterns of nutrient cycling are unknown. Equally unknown is the influence of these variations on flowering and seed production of target plant species along the moisture gradient.

The needs of RCWs are well known, but virtually nothing is known of community dynamics between the plants at the base of the food chain and the RCW at the top, or within the consumer community at the top beyond the RCW (USFWS, 2003). Greater understanding is needed of how intensive management for RCW may affect other species. One component of the monitoring planned for the Terrestrial Module, vegetation sampling, is tied to these research objectives in providing data on changes in the plant community over time and across the soil-moisture gradient in response to PB and management of habitat for RCWs. The second component, monitoring of changes in land use and land cover, serves the Coastal Wetlands and Aquatic/Estuarine modules in providing data required to interpret monitoring and research results related to flow and nutrient dynamics. The need for a larger monitoring program in the Terrestrial Module is obviated by other ongoing monitoring efforts within terrestrial environments on MCBCL, efforts which will be integrated with DCERP activities. However, an objective of the research proposed for the Terrestrial Module is to identify indicator species that might enable efficient monitoring of habitat condition and hence provide MCBCL with additional monitoring capabilities in the future.

6.4.2 Terrestrial Module Monitoring Objectives and Activities

Terrestrial monitoring will focus on two general objectives. The first will be the development of a network of permanent vegetation sample plots representing the full range of environmental gradients and management activities at MCBCL. Data for each geo-referenced plot will include plant abundance, composition and diversity, as well as flammable fuel loads and a few key soil characteristics. This monitoring will be accomplished by combining already-existing geo-referenced data with additional sample plots. Plots will be re-sampled approximately every 5 years (re-sampling will not occur during this funding period). The second objective will be an annual GIS-based assessment of changes in land use and land cover. This assessment of land use/land cover change will complement the field vegetation data collection, validate modeling efforts and provide a comprehensive estimate of ecosystem change at regular intervals for MCBCL. Data layers will include buildings structures, roads and impervious surfaces, and management activities. **Table 6-10** summarizes the monitoring activities of the Terrestrial Module.

Table 6-10. Terrestrial Module Monitoring Components

Components	Variable	Spatial Scale	Temporal Scale
Flora	Species composition, diversity, and distribution	Approximately 100-0.1 ha sample sites distributed across MCBCL	Initial sample Years 1 and 2; 5-year intervals thereafter.
Forest floor and soil	Fuel load, soil bulk density, pH, organic matter	Associated with each of the above	Initial sample Years 1 and 2; 5-year intervals thereafter. Soil samples Years 1 and 2

Components	Variable	Spatial Scale	Temporal Scale
Land cover and land use change	Land cover types, including vegetation communities, roads, building and land use designations.	Local and regional - to include lands within the watershed surrounding MCBCL	Annual Landsat ™ data. IKONOS data in Years 1 and 4

Recovering the Base's RCW population is a high management priority, and determining how the plant and animal community responds to management for RCWs, especially use of prescribed fire, across the soil-moisture gradient is a critical knowledge gap in the Terrestrial Module. RCW recovery necessitates monitoring the RCW population, and monitoring foraging habitat provided to this population [indeed the U.S. Fish and Wildlife Service requires it in order for the Base to adhere to the ESA (USFWS, 2003]. RCW monitoring also is important to the research proposed for the Terrestrial Module, understanding management effects requires such monitoring in order to interpret the relationship between management to benefit RCWs and community dynamics. Monitoring of the RCW population will be conducted under a separate contract, funded by MCBCL, as part of the long-term studies of the RCW population by the Co-leader for the Terrestrial Module, Jeff Walters.

RCW monitoring includes maintaining a completely marked population of birds, determining each breeding season the number of active territories, unpaired males and groups, recording breeding attempts and associated data (clutch size, brood size, nesting success, number of young fledged) and determining the number, identity and status (e.g., breeder, non-breeding helper) of all group members in all groups. Both data collected during DCERP and historical data collected previously (1986–2007) will be included in the DCERP data and information management system.

MCBCL monitors foraging habitat for RCWs as part of its forestry and wildlife operations. This monitoring also is an integral part of the research proposed for the Terrestrial Module, in that it will provide a measurement of RCW foraging habitat quality, to which more detailed data collected as part of the proposed research will be compared. One objective of the research is to identify an efficient means to measure RCW foraging habitat quality over a large spatial extent.

Table 6-11 summarizes the estimated level of effort for each of the key personnel during the first four years of Phase II for the monitoring activities previously listed in **Table 6-10**. A specific list of the personnel for each monitoring activity is located within the Methods section of each monitoring activity described in Section 6.4.4 (*Terrestrial Module Monitoring Components*).

Table 6-11. Terrestrial Module's Estimated Staffing of Monitoring Activities

Personnel	Time in months/year			
	Year 1	Year 2	Year 3	Year 4
Norm Christensen	0.5	0.5	-	-
Pat Halpin	0.5	0.5	0.5	0.5
Graduate Student (1)	8	8	8	8
Undergraduate Student (1)	2	2	-	-
Technician (1)	3	3	3	3

6.4.3 Benefit to MCBCL

The vegetation monitoring proposed will help MCBCL improve the effectiveness of its PB program in conserving and restoring terrestrial communities and of its efforts to provide high quality habitat for RCWs. The land cover/use analysis provides baseline understanding of changes in the distributions of

ecosystems, built structures and human activities on and surrounding MCBCL. This change analysis will provide important information relevant to all modules and research projects, and it can ultimately form part of the foundation for the future development of base-scale simulation models and decision tools.

6.4.4 Terrestrial Module Monitoring Components

6.4.4.1 Changes in plant species composition, diversity, and distribution

6.4.4.1.1 Objectives

The Terrestrial Module monitoring will provide a uniform, geographically explicit database for plant species composition and abundance that will be the basis for assessing regional and site specific changes in plant communities (and associated parameters such as fuel conditions). Because, individually and in groups (e.g., communities or guilds), plant species are high fidelity of indicators of variation in the physical environmental template (soils, hydrology, site fertility etc.) and of the effects of human activities that may affect that template (see Christensen [2000] for a discussion of these relationships), a network of permanent vegetation plots provides a useful barometer of habitat condition. Furthermore, data on species composition is critical to the assessment of potential changes in the abundance of species interest, including threatened and endangered species and invasive, non-native species. Spatial and temporal variation in species composition and diversity not only provide important indices of ecosystem health, but are often diagnostic of specific environmental effects such as soil compaction or altered fire regimes. Finally, as the ecosystems' primary producers, the community of plants in any location is the ultimate source of carbon energy and defines the structure of habitat for a diverse array of consuming and decomposing organisms. Thus, detailed monitoring of plant communities is central to understanding possible local and landscape-level changes in habitat for species such as the RCW.

6.4.4.1.2 Relevance to the Base

Data on vegetation variation and change are relevant to the effects of virtually all terrestrial stressors. Buildings and roads alter hydrology at a variety of scales in ways that may have immediate and long-term impacts on plant communities at a variety of spatial scales. Military maneuvers within individual communities may alter fire regimes or compact soils in ways that influence the survival of plant species. Even remote, non-military activities may influence plant communities. For example, changes in air quality that influence nitrogen deposition or long-term changes in climate may slowly alter site fertility and produce ecosystem changes that can only be detected by spatially explicit long-term sampling. Changes in fire regimes and forest management (forest thinning and clear cutting) have significant effects on plant composition and species diversity, and plant communities are sensitive to changes in the impacts of episodic disturbances, such as hurricanes. Plant communities provide a means of understanding legacy effects on landscapes, such as patterns of past land use or hydrologic modification (Christensen, 1989).

6.4.4.1.3 Scale

Each sample location will represent the composition, abundance, and in the case of trees, the size distribution of species at that site and at a specific sample time. Thus, individual samples are based on 0.1-hectare plots. Plots will be arrayed in a network to represent the full range of physical environments and key disturbance regimes on the Base. This will allow assessment of changes across the entire installation or for particular subunits defined either by ecosystem type (e.g., longleaf pine forest) or management regime (e.g., areas subject to regular military maneuvers or altered fire regimes). Because the sampling protocol used here is the standard used as part of the North Carolina Vegetation Survey (Peet et al., 1998), changes in vegetation at both the plot and the installation level can be set in the context of regional variation and change.

6.4.4.1.4 Linkages within the Module and among other Modules' Monitoring Components

This dataset will provide the basis for assessment of changes in habitat for other species, including threatened species such as the RCW and invasive species. Fuels will be quantified at each sample location, providing a measure of potential fire risk and behavior, which are important inputs to atmospheric measurements and models. Because they are spatially explicit, these data will be included as a key layer in the land use/land cover change monitoring project (Section 6.4.4.2). Because many of these plant communities are adjacent to nearby wetland and estuarine ecosystems, changes in the status of these communities will be relevant to Coastal Wetlands and Aquatic/Estuarine Modules. This monitoring program has the potential to extend MCBCL activities and RCW management across ecotones and into wetter portions of the soil-moisture gradient.

6.4.4.1.5 Methods

Spatial/Site Locations

Specific spatial locations of historic sample plots have not yet been compiled. This will be the highest priority for the first sample year. Once these data have been collated and the precise geographic locations of the sites have been established as a GIS layer, the site locations will be mapped and examined for key gaps in the overall datasets. Such gaps might include underrepresented environments or geographic locations, sites of known strategic importance (e.g., areas of special interest to managers or to other DCERP modules), or unique habitats (limestone wetlands, red cedar bogs). Sites will be selected for establishment of additional permanent plots in collaboration with installation personnel to ensure that they capture management priorities (Section 6.4.4.1.2) and avoid conflicts with military activities (e.g., impact areas).

Temporal Considerations

Supplementary sampling of historic sample plots and establishment of new sample plots will occur during the first year of the monitoring program. All plots will then be re-sampled for vegetation and fuels on a 5-year rotation. No re-sampling will occur on this funding cycle. The pace of vegetation change is comparatively slow and more frequent sampling is not warranted except in the case of specific impacts such as disturbance to a particular site, or a major event such as a hurricane.

Personnel

- Senior Researchers: Norman Christensen
- Undergraduate students: 2 summer field assistants
- Summer graduate student assistant (1)

Parameters/Variables

- Tree (snags) density and size-class distribution by species
- Shrub (< 1 cm diameter at breast height [dbh], > 1 m tall) density by species
- Herb (plants < 1m tall) cover by species
- Logs and woody debris
- Fuel load
- Soil order and series
- Soil bulk density, pH, and organic matter

Field and Laboratory Procedures

Sampling Design and Collection. The basic dataset for this monitoring activity will come from data previously gathered on the installation by the North Carolina Natural Heritage Program, the North

Carolina Vegetation Survey (Peet et al., 1998), as well as current sampling efforts such as that being undertaken in the collaboration between The Nature Conservancy, the Student Conservation Association and the LandFire program. The samples of interest are those based on 0.1 hectare sampling plots that have been evaluated using the North Carolina Vegetation Survey protocols. Approximately 50 of these sample plots, referred to here as "historic sample plots," are thought to have been established since about 1999. We will also be working with the Base to identify other vegetation sample data which could serve as the basis for additional permanent plots. The assembly and assessment of these data into a single unified installation dataset will be a priority task for the first monitoring year. Note that some historic sample plots may be missing some of the data elements described below (e.g., fuel load estimates or soil data), and supplementary sampling will be done at these locations to fill data gaps.

Approximately 30 additional samples will be located as following the general sample protocol that was used in historic sample plots (Peet et al., 1998). Individual plots are located within sample stands so as to avoid obvious vegetation transitions and represent relatively uniform environmental conditions. Within a 20×50 meter (0.1 ha) plot, all living and dead stems (> 1 cm dbh) are tallied by species and dbh. For the herbaceous layer, the plot is further subdivided into ten 10×10 meter plots. Four of these plots are termed "intensive," while the other six are referred to as "residual." Each intensive plot is sampled for herbaceous species (recorded by % cover) with 5 nested plots, increasing sizes of $0.01m^2$, $0.09m^2$, $1.0m^2$, $9m^2$, and $100m^2$ in two corners of the intensive plot. Once intensive plots are sampled, the residual plots are surveyed to identify all species not found in any of the four intensive plots. In addition to herbaceous vegetation, important legacies such as rotting logs and woody debris will be assessed by size class using line intercept transects across the plot (e.g., Harmon et al., 1986). Finally, fuel condition will be assessed in each plot using standard U.S. Forest Service protocols for fuel load estimation for the National Fire Danger Rating System (NFDRS) model (Andrews and Bradshaw, 1997). All plot data will be deposited in VegBank.org, the national plot archive.

In addition to vegetation data, a 1-m $\times$ 5-cm soil core (taken with a piston type sampler) will be examined at each site in order to classify the soil by general order and series. Soil from five 5-cm diameter, 10-cm deep cores will be composted and measured for bulk density (volume/dry weight), pH (glass electrode in saline slurry) and organic matter (weight loss on combustion at 500 ºC). These basic soil data have been shown to have a high correlation with the distribution of many coastal plain plant species (Walker and Peet, 1986; Christensen et al., 1988; Christensen, 2000; Peet, 2007).

Equipment Used. Field sampling will require standard sampling devices such as meter tapes, diameter tapes and clinometers. Soil will be sampled using a piston-type soil corer. Laboratory analyses will require a pH meter and analytical balance.

Data Management

Field data sheets will be scanned to electronic media and stored in the DCERP Document Database and with managers at MCBCL. Original data sheets will be archived with the library at Duke University. Data will be coded in a common format using Excel and cross-checked against original data sheets. Once they have been error-checked, Excel databases will be stored in the DCERP data and information management system.

6.4.4.1.6 Data Analysis, Products, and Outcomes

Data will be summarized by plot in terms of such measures as tree density and volume, herbaceous cover and diversity, legacy structures and fuels using the standard summary statistical measures in Excel. Compositional variation among individual plots will be assessed using PC-ORD software (McCune and Medford, 1999). Specific ordination techniques vary with questions and needs, however, non-metric multidimensional scaling is especially robust and will likely be favored for most analyses (McCune et al.,

2002). Spatial and temporal vegetation changes (composition, diversity, fuel loads) will be evaluated using Mantel and partial Mantel models (Mantel, 1967).

Normal values for such measures as species composition or diversity vary widely across the range of MCBCL environments, and threshold values for individual ecosystems have not been established. Fuel load measures will be used to assess plot and area fire risk using the NFDRS model (Andrews and Bradshaw, 1997).

6.4.4.2 Assessment of Land Use/Land Cover Change

An assessment of land use/land cover change will be completed to complement the field vegetation data collection, validate modeling efforts and to provide a comprehensive estimate of ecosystem change at regular intervals for MCBCL. Change detection identifies change in the spectral qualities at a given location on the surface from one image to the next in a time sequence. This spectral change then must be related to the change types of concern, such as vegetation loss. Satellite image-based detection can readily identify gross change, such as new construction and human activity that alters the landscape over large areas. Success in detecting more subtle change, such as vegetation successional patterns, species composition, or vigor through time in a relatively small area like MCBCL, will depend largely on the nature, size, and magnitude of the change and the resolution on the remote sensing data used. Resolution in this context refers not only to spatial resolution, but also temporal (time interval) and spectral resolution; all will affect the success of change detection.

A multi-resolution change detection analysis of landcover that is directly linked to watershed drainages will most effectively achieve the goals of the Terrestrial Module. The use of a medium scale and resolution dataset (28.5m multispectral) Landsat TM data annually will provide a broad, regional context that will include an area beyond the boundary of MCBCL, if possible to include the entire New River and surrounding watersheds. A finer scale and resolution dataset such as IKONOS (4m multispectral and 1m pan-chromatic) semi-annually will allow identification of much smaller change patches. The change information at both scales will be linked to local, LIDAR derived watershed drainage units within and beyond MCBCL. Each grid cell (pixel) location in the change detection framework will be assigned a hydrologic flow location, allowing for the direct linkage of landcover change to downstream processes and across different sectors of the monitoring program. The watershed context will creates an ecologically significant unit of study and provide a natural linkage to the Aquatic/Estuarine and Coastal Wetlands modules.

Landsat TM images will be used to address change at medium resolution. This will provide a comprehensive annual baseline for the region. A winter/summer pair of images for each year allows for annual analysis of landcover status but also monitoring of the composition of deciduous versus evergreen vegetation. This cross-seasonal approach also allows for long-term studies of successional trends at a regional scale (McDonald et al., 2007). This system is inexpensive and immediately available for MCBCL. Landsat data is collected twice monthly for each 180-km × 180-km scene defined on the earth’s surface. The data is archived and has a long history. This would allow for future work to expand the temporal sequence of the Landsat change data back in time to the early 1980s. In addition, MCBCL looks to be contained fully in two overlapping Landsat scenes, 15/36 and 14/36, as shown below (**Figure 6-13**). This greatly improves chances of acquiring an image covering MCBCL, with four opportunities a month rather than just two. However, both scenes would be necessary to cover the entire White Oak watershed. If adequate scenes exist, both 15/36 and 14/36 will be acquired in summer and winter, for a total of 4 TM scenes annually.

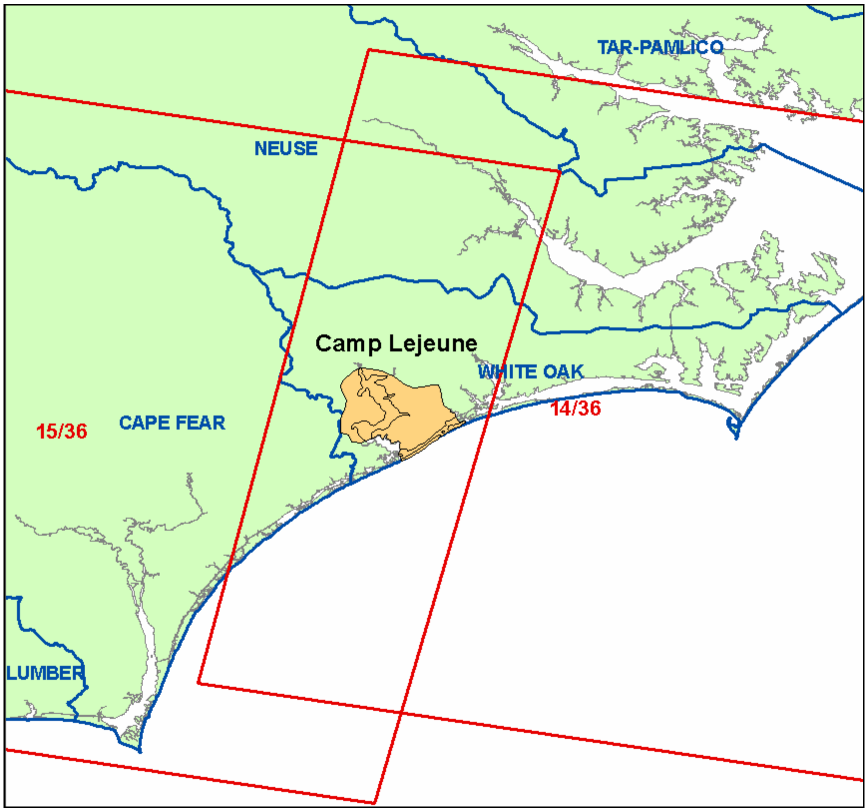


Figure 6-13. Camp Lejeune, NC and associated Landsat scene and watershed boundaries.

To identify smaller change patches, higher resolution imagery will be necessary. Several private satellites have been launched in the last 5 years that range in spatial resolution from 4m to about 2.5m. These satellites can be commissioned to acquire images within the time frames desired. The imagery is more expensive and does not provide a past temporal sequence—these satellites are not collecting data unless tasked; a past dataset is unlikely to exist. These satellites include IKONOS, Orbview and Quickbird, among others. This data will be acquired semi-annually to examine specific, fine scale patterns. As with the Landsat data, these finer scale patterns will be linked to the local, LIDAR derived watersheds to observe potential impacts within a flow basin. IKONOS has multispectral data with a spatial resolution of 4m. While IKONOS is a likely choice, other satellite systems with sufficient spatial resolution will be examined for the best combination of scene size, spectral and spatial resolution, and cost.

Figure 6-14 below provides a simple timeline of image acquisition for both the TM medium resolution data and the high resolution data (perhaps IKONOS).

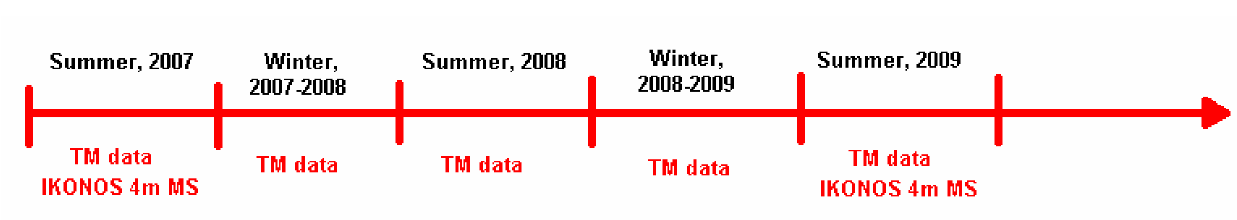


Figure 6-14. Timeline for image acquisition.

Other imagery may also become available at little to no cost. MCBCL may have or have access to imagery that could be applied to this work. Other SERDP-funded projects (SI-1471, SI-1472) doing work

on Fort Bragg and MCBCL plan on using ASTER imagery (15m multi-spectral data) and LIDAR data that may be available for DCERP. If Landsat data of MCBCL is unavailable, ASTER is a likely replacement for mid-resolution work.

Land use/land cover maps will be useful as a reference. Several exist for North Carolina with a 30m spatial resolution. A national dataset of land use/land cover exists for the early 1990s and the early 2000s. A North Carolina state product for the early 1990s is available. Other products will be examined, such as the North Carolina GAP Vegetation Mapping Program. Land use/land cover specifically of MCBCL may exist as well.

This change detection work at multiple scales will all be linked through a watershed approach. LIDAR data will provide high resolution elevation data. Coastal regions require high resolution DEMs to model flow because it is flat and small changes determine the flow patterns. Typical USGS DEMs would be inadequate. The state of North Carolina has finished a LIDAR-based DEM set for the entire state. The state-wide product is available with a resolution of 50 ft for 'hydro corrected' (corrected with respect to stream location) DEMs. This data will be used to produce the local watershed of the MCBCL region. This provides ecologically meaningful unit(s) and a method to integrate the change results with other aspects of DCERP. With this data, 'flow paths' can be created, where the flow direction downstream is known for every 50ft pixel in the watershed. The ArcHydro package for ArcGIS will be implemented for this modeling.

6.4.4.2.1 Objective(s)

The Landscape Change Detection monitoring activity will identify change at two scales:

- Moderate resolution regional change within the New River watershed.
- High-resolution change within MCBCL.

Regional change will be examined annually using Landsat TM data. This will identify change that occupies the majority of a TM pixel, $900m^2$. Within MCBCL boundaries, a higher resolution system such as IKONOS data will be used to locate change patches semi-annually. IKONOS data will identify change that occupies the majority of a $16m^2$ pixel.

The cross-scale change detection will continue for the time period of DCERP, providing a temporal change sequence of the region and MCBCL. Any given location can be followed through time for its unique temporal change signature. In conjunction with the Aquatic/Estuarine and Coastal Wetlands Modules, highly accurate LIDAR derived flow paths will be developed to access the potential impact of changes downstream.

6.4.4.2.2 Relevance to the Base

MCBCL is facing a variety of mandates to manage for endangered species through an ecosystem-based management approach. The RCW is the most well know example. Two SERDP-funded projects are currently examining this topic (SI-1471, SI-1472). Ecosystem management for endangered species often revolves around the loss and conversion of habitat. Temporal change patterns provided by this monitoring effort, potentially going back in time, as well as forward, directly address this problem. Knowledge of the change patterns in and near MCBCL is crucial for the difficult management decisions facing MCBCL.

6.4.4.2.3 Scale

Installation to Regional.

6.4.4.2.4 Linkages within the Module and among other Modules' Monitoring Components

Change detection work will be done at two scales, both spatially and temporally. An annual change detection using 900m^2 minimum change patches will examine regional change within the New River and surrounding watersheds. Finer scale change patches within MCBCL itself will be examined with high spatial resolution multispectral imagery semi-annually.

6.4.4.2.5 Methods

Spatial/Site Locations

Change detection will be processed for MCBCL and, provided adequate imagery is available each year, the entire White Oak River Basin (including the New River) (see **Figure 6-13).** This is a landscape level methodology that will encompass most if not all other field sites. This will allow for the analysis of the affect of change on any other sampled variables, where appropriate.

Temporal Considerations

Four Landsat TM scenes will be acquired yearly, scenes 14/36 and 15/36 for both summer (May or June) and winter (December, January, or February). High resolution imagery, perhaps IKONOS, will be acquired for summer (May or June) in 2007 and 2010. Imagery will be collected as near to anniversary dates as possible.

Personnel

- Senior Researcher: Pat Halpin
- Geospatial/Remote Sensing Analyst: Peter Harrell
- Graduate student intern (1)

Parameters/Variables

Parameters in change detection are the image pixels themselves. Spectral differences from time 1 to time 2 on a pixel-by-pixel basis are examined and recorded. These raw changes must be interpreted to provide meaningful results, i.e., 'vegetation loss'.

Procedures

- Change detection will depend on the acquisition of high quality cloud-free imagery of the Base and White Oak basin. Anniversary dates minimize differences from year to year and, for effective change detection, winter/summer pairs (for annual TM data) improve the success of the change detection. Winter scenes are less problematic; December, January and February are all adequate as there is little vegetation activity and winter skies more cloud-free and contain less water vapor/haze. Summer haze and clouds are a significant problem. Early summer tends to be the best to limit haze and clouds. May is the least cloudy month and tends to have lower humidity, and thus is the target for the summer time sequence. Early June will be acceptable if May is not available.
- Landsat TM data is collected every 16 days, approximately twice a month. The sensor is quite stable, but atmospheric conditions will dictate success at collecting a time sequence. As the Base is only a portion of two different scenes, it is not necessary that the full scene be cloud-free; only the area over the White Oak watershed. This greatly improves the chances of collecting cloud-free data over the Base and the White Oak watershed during the overflights in May or June. IKONOS and most other high resolution data are collected upon request. IKONOS guarantees at best < 20% cloud cover, which will be a difficulty for the change detection.

- Images will be processed change detection produced with the computer facilities of the Nicholas School of the Environment, Duke University.

6.4.4.2.6 Data Analysis, Products, and Outcomes

Images will require certain pre-processing steps, dependent on the specific image source, typically precise rectification and radiometric normalization to calibrate each scene. This is critical to the change detection success. Each scene used in the temporal sequence must align with an accuracy of less than half of a pixel to assure correct relative position. Radiometric normalization assures that the pixel values are consistent through time. The radiometric differences are minimized by the use of anniversary dates of imagery, all May images for example. This means illumination will be similar as the sun angle will be same within a small variance. Ground conditions will also be similar. Finally, this gives the best chance for good atmospheric conditions. However, additional radiometric processing is typically required to adjust for atmospheric differences and small differences in the sensor itself.

Landsat data is a known quantity. This will be precision rectified to a horizontal accuracy of less than 15m (half a pixel). Radiometric/atmospheric correction is then applied using best current information and calibration coefficients.

The high resolution data will present some different processing challenges. A system like IKONOS will require multiple images to cover MCBCL. All images used in the mosaic must also be normalized, in addition to the temporal normalization and precision rectification. The exact methods will depend on which satellite data is ultimately used.

There are many change detection methods. The choice of specific methods depends to a considerably extent on what type of change must be identified. This approach will use a combination of Change Vector Analysis (CVA) and simple band differencing techniques. This is less labor intensive than methods that require a landcover classification of each time step. Classification and accuracy assessment of three scenes every 2 years would be prohibitively costly in both time and resources.

CVA is a radiometric technique that detects all change present in a pair of multispectral images (Malila, 1980). The CVA technique typically uses a spectral enhancement referred to as the ‘tasseled cap’. This was originally developed for use with the Landsat Multispectral Scanner (Kauth and Thomas, 1976). The tasseled cap consists primarily of two new spectral dimensions called ‘brightness’ and ‘greenness’ in place of the original satellite bands. The original bands of the image can be considered as an N-dimensional space, where N is the number of bands. These axes can be rotated to create the new axes in the tasseled cap space. This new space is orthogonal, with the brightness and greenness axes optimized for vegetation studies (Kauth and Thomas, 1976; Crist and Kauth, 1986). Every pixel can be mapped in this space from the initial and final images of a change pair. Each pixel pair then has a magnitude (distance between the points) and direction of change in terms of brightness and greenness. The magnitude and direction of change provides information on any change in land use on a pixel-by-pixel basis (Johnson and Kasischke, 1998). CVA has the advantage of not requiring the scenes to be classified prior to the analysis, a very time consuming and error prone procedure. This is also the primary disadvantage; the type of change is not explicitly identified. The user must interpret the change in terms of the magnitude and direction. However, once the user identifies what type of change is of concern, simplifications to the CVA data can often be made to ease the identification of change type.

Several studies have employed CVA successfully, including a recent study done on the Albemarle-Pamlico Basin (Lunetta et al., 2004). **Figure 6-15** shows a simple result from a CVA study conducted by the Nicholas School Geospatial Analysis group using a time sequence of Landsat images of the Upper Neuse basin as a pilot project for the Consortium of Universities for the Advancement of Hydrologic Science, Inc. The CVA used May images from 1986, 1991, 1997 and 2000. Colored patches indicate a

loss of vegetation, with color indicating the persistence of the loss. Red is a loss in the 1986–1991 time period that persisted as non-vegetated to the end date in 2000. Pink was a vegetation loss in two of the three time periods (typically 1991–1997 and 1997–2000), and green in just one. In this example, green represents both sites that lost vegetation in the 1986–1991, or 1991–1997 period, then re-vegetated in the following period, as well as loss in the last time period 1997–2000, for which we do not know the fate without an additional change pair. Clear in this data is the construction of the I-540 outer beltline around Raleigh, NC. The western portion, in red, was constructed during the first change period (1986–1991), the pink portion on the east was constructed in the second change period (1991–1997). Also visible is construction at the Raleigh-Durham airport and new suburban development, as well as small forest harvest units.

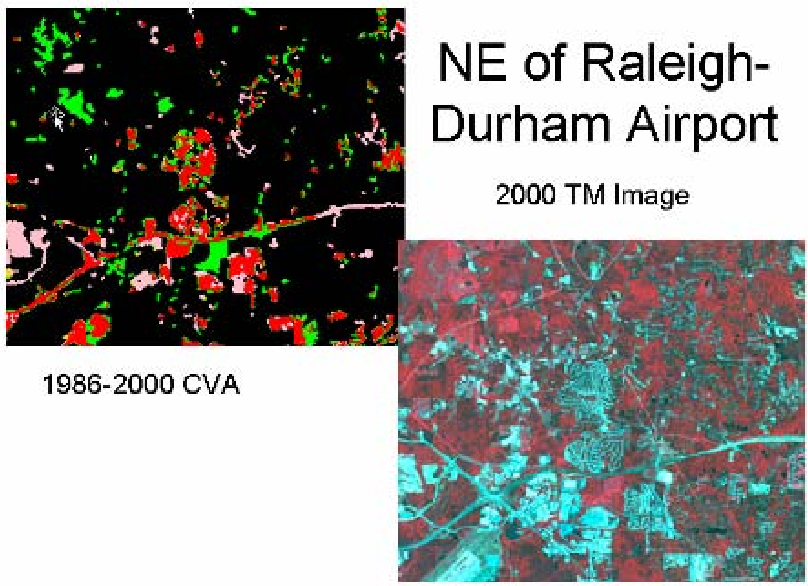


Figure 6-15. Landsat CVA near the Raleigh-Durham Airport.
Initial image is from 1986 and end date image is from 2000 in this example.

With a sufficiently dense time sequence and a long time frame, change detection can also be applied to processes. Change can be tracked, for example, from 'pine' to 'cleared', to 'brush' and back to 'pine' and then to 'hardwood' with a sufficiently long time series. McDonald et al. (2007) used a chronosequence to identify a successional transition from pine to hardwood in the Duke Forest.

This will result in a variety of products. Change analysis will provide data on the spatial location and size of change patches on the landscape. Initial products will include yearly change patches at a spatial resolution of $900m^2$, (28.5m TM pixels) for the White Oak watershed (provided adequate cloud-free images can be acquire; if not a smaller region will be completed) and semi-annual change patches at a spatial resolution of between approximately $6.25m^2$ to $64m^2$, with the most likely alternative being IKONOS data at $16m^2$ pixels, for locations on MCBCL. As a time sequence is built, additional products showing the temporal change sequence for both scales of data will be available.

6.5 Atmospheric Module

6.5.1 Introduction

The atmosphere represents one of the major pathways for the transport of nutrients and potential pollutants into and from terrestrial and aquatic ecosystems (Lawrence et al., 2000; Paerl et al., 2002). It is

also one of the primary pathways for the redistribution of nutrients and potential pollutants observed along coastal areas (Melillo et al., 1989). Because the atmosphere is not passive, transformations of various gaseous and particulate species, while undergoing transport, broaden the scope of emissions that need to be quantified. These transformations occur in the presence of other atmospheric constituents derived from local and distant regional sources, further complicating attempts to successfully attribute or predict impacts from emissions associated with MCBCL activities on neighboring communities. The vegetative cover of the terrestrial ecosystem at MCBCL represents a large surface area that promotes atmospheric deposition. Atmospheric deposition, in turn, represents an input into both the terrestrial and aquatic ecosystems. Nutrients and pollutants from atmospheric deposition are incorporated into internal nutrient cycles within the respective ecosystems at the Base, exerting their potentially stressful influence on various time scales, depending on the nature of the ecosystem itself and activities undertaken by MCBCL staff to optimize their military mission. Depending on the activity and function of the deposition surface, certain air pollutants potentially act as ecosystem stressors, such as acid rain and ozone. In EPA's Criteria Documents for ozone and particulate matter (PM), the EPA has compiled and evaluated a substantial body of research work from the past 30 years demonstrating the direct and indirect effects of ozone and fine and coarse PM on vegetated and aquatic ecosystems (U.S. EPA 2004b, 2006b). These and more recent findings prompted the EPA to propose revision of the 1997 NAAQS rule for ozone by including a cumulative standard aimed at protecting vegetation during the growing season (EPA 40 CFR Part 50). The proximity of MCBCL to the coastal environment adds another level of complexity because the presence of marine-derived sea salt aerosols imposes a natural gradient of deposition across the Base and also exerts an influence on atmospheric transformations not typically encountered further inland (Andreae et al., 1986, O'Dowd et al., 1997).

The input of nutrients and potential pollutants via atmospheric deposition interacts with most key terrestrial and aquatic ecological processes occurring at MCBCL, as illustrated in **Figure 6-16** and as reported for similar ecosystems (Van Der Salm et al., 1999; Lawrence et al., 2000). Atmospheric deposition is a direct source of inputs to the open water surfaces of the aquatic ecosystem, as well as to the vegetation surfaces of the terrestrial ecosystem, with the frequency and composition of these inputs posing an important influence on flora diversity. For example, changes in the dominant forms of a given nutrient (e.g., DO) over time will lead to shifts in the dominant flora within the aquatic ecosystem (Paerl et al., 2002), whereas shorter-term vegetation effects to ozone exposure have been captured by concentration-weighted cumulative exposures to ozone on an hourly basis (U.S. EPA, 2006b). The aquatic ecosystem also is impacted by atmospheric deposition after it is filtered and altered by passage through the terrestrial ecosystem. This impact occurs on all time scales, ranging from rapid inputs following large rainfall events (runoff) to slow but critical changes in baseflow from the superficial aquifer (Hunsaker et al., 1994; Osgood and Zaeman, 1998). It may not always be immediately evident which impact is playing the dominant role in forcing change within the aquatic ecosystem. Similarly, terrestrial ecosystem impacts that will become evident from the satellite-supported seasonal evaluations may be due to exposure to a complex combination of long-term climatological stress (e.g., temperature, drought) and shorter-term air pollutant stress (oxidants and metals). Heavy metals of fine PM have been associated with forest decline partly due to their correlated deposition pattern, and in vitro studies found particularly iron, aluminum, nickel, zinc, magnesium, and lead playing most important roles in tree injury and decline (U.S. EPA, 2004b).

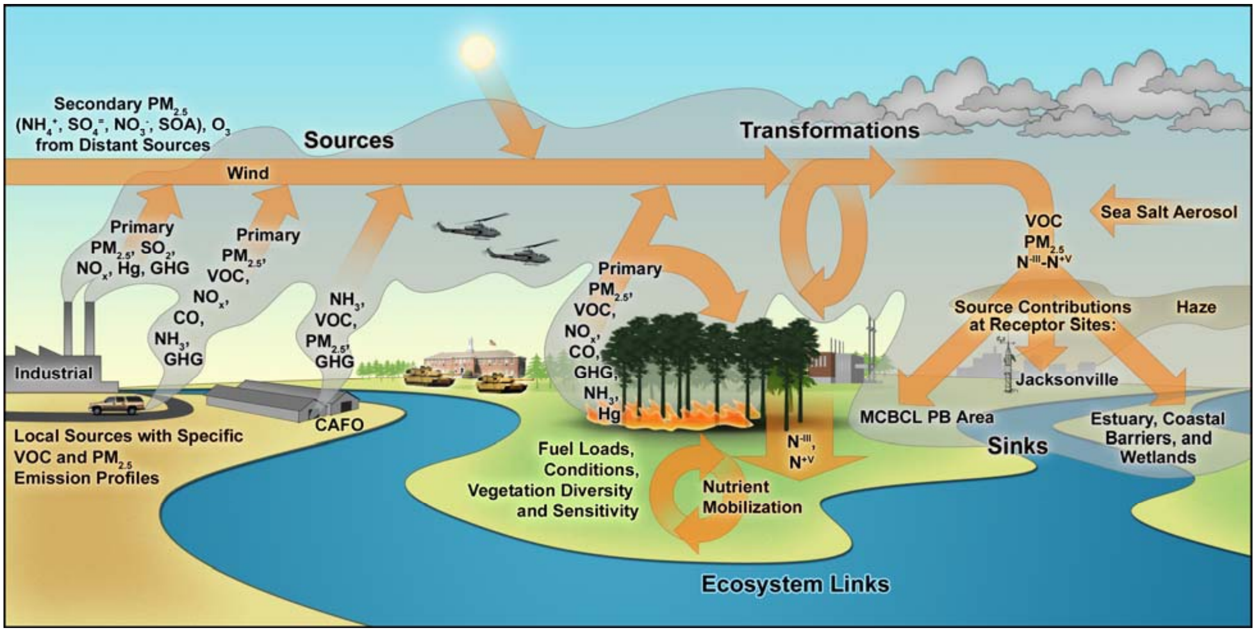


Figure 6-16. Conceptual model for the Atmospheric Module.

Fire is a natural part of this landscape, and natural fire regimes (e.g., frequency, intensity, and season) vary across this soil-hydrology-vegetation gradient, from frequent surface fires in longleaf pine savannas to relatively infrequent and intense crown fires in pocosin (Kodama et al., 1980); however, PB was used by native Americans for improving access, hunting, and farming and was adopted by the early European settlers. By the 1980s, PB had become the dominant land management tool in the southeastern United States, and MCBCL managers have implemented this technique to reduce wildfire risk, manage range and forest ecosystems, and provide and maintain terrain for training and testing. PB is also mandated by the ESA to recreate the natural fire regimes needed to maintain the health of native forest ecosystems and, thus, to protect the habitat of threatened and endangered species. Despite its essential ecosystem benefits, PB is a major source for fine particulate matter ($PM_{2.5}$) and other air pollutants due to its incomplete and largely uncontrolled combustion process, which involves flaming and smoldering phases with different effective fuel consumption, unknown ecological sensitivities toward burning conducted in growing versus dormant seasons (Johnson et al., 1998), and unclear ecological benefits on larger spatial and temporal scales (Maclean et al., 1983; Raison et al., 1985). Certain fuel and fire meteorological parameters influence the emissions from the different combustion phases, which in turn participate in transport processes within the atmospheric boundary layer, causing air quality impacts on local to regional scales (Lee et al., 2005, Friedli et al., 2007).

Dry deposition of atmospheric constituents, either nutrients or pollutants, is directly dependent on their ambient concentration near the ground. These concentrations are influenced by different anthropogenic and biogenic sources; meteorological conditions driving their atmospheric dispersion and transformation; and sinks (see **Figure 6-16**). Among the six criteria air pollutants regulated for the protection of human health under 40 Code of Federal Regulations (CFR) of the Clean Air Act (CAA), O_3 and $PM_{2.5}$ are the most difficult to control because they are products of complex atmospheric formation processes involving heterogeneous photo-chemical reactions of certain precursors (U.S. EPA, 1996; U.S. EPA, 1997; Seinfeld and Pandis, 1998). Ammonia (NH_3) and volatile organic compounds (VOCs) are of particular importance because of their precursor role in these processes yielding secondary inorganic and organic aerosol (NH_4^+, SO_4^{2-}, NO_3^-, and secondary organic aerosol [SOA]), respectively. Other CAA-regulated criteria pollutants are sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and lead (Pb). Increased nitrogen

oxides and ammonia emissions and the formation of $PM_{2.5}$ alter patterns in atmospheric deposition through changes in the amount, composition, and distance of transport.

6.5.2 Atmospheric Module Monitoring Objectives and Activities

The objective of the Atmospheric Module's monitoring activities is to characterize the role of air quality in MCBCL's ecosystem by capturing meteorological and climatological processes and their occurrence in different temporal and spatial scales in support of various research projects that consider and depend on certain biosphere-atmosphere interactions (**Table 6-12**). **Figure 6-16** depicts the crosscutting nature of atmospheric processes and constituents on the terrestrial, aquatic/estuarine, coastal wetlands and barrier island ecosystems. Characterization of the air quality's role requires a good understanding of atmospheric dynamics and composition, including the identification of air pollutants, their sources, their distribution and dispersion mechanisms in the boundary layer (BL) above the ecosystem and their deposition processes following wet and dry deposition pathways. EPA's Criteria Documents for O_3 and PM demonstrate the direct and indirect effects of O_3 and fine and coarse PM on vegetated and aquatic ecosystems (U.S.EPA 2004b; 2006b). The main results indicate that the coarse PM typically are richer in crustal elements, including aluminum, silica, iron, calcium, and magnesium and deposit more rapidly to vegetation surfaces than fine PM dominated by species subject to secondary atmospheric formation processes such gas-to-particle conversion and nucleation. Therefore, chemical speciation of the fine and coarse PM fractions will allow distinction between different PM sources such as wind blown soil dust, including dust originally released by near-by military training vehicles dominating the coarse fraction, and air masses of regional character rich in fine PM (sulfate, nitrate and ammonium).

Table 6-12. Atmospheric Baseline Monitoring

Component	Variable(s)	Temporal Scale	Spatial Scale
Meteorology	WS, WD, BP, RH, PAR	Hourly	3 existing stations: Riseley Pier (south), GSRA (west), and New River Air Station (north)
Meteorology	Precipitation	Event-based	9 total (6 new sites will be deployed)
EPA criteria pollutants	O_3	Hourly	3 existing stations: Riseley Pier (south), GSRA (west), and New River Air Station (north)
EPA criteria pollutants	PM_{10} and $PM_{2.5}$ mass	Minute to hourly	3 existing stations: Riseley Pier (south), GSRA (west), and New River Air Station (north)

Due to the large vegetation gradients that exist in MCBCL's ecosystem, and partly also due to the observed senescence of loblolly pine along with the anticipated complex dynamics of atmospheric physical and chemical processes shaping a highly variable abundance of O_3 and fine and coarse PM concentrations, the Atmospheric Module's monitoring activities will focus on the capturing the variability associated with local and regional transport. Ambient concentration of coarse PM (PM_c) will be determined from the difference of measured PM_{10} and $PM_{2.5}$ mass and composition. In the context here, $PM_{2.5}$ represents the *fine* PM mass fraction.

The monitoring activities of the Atmospheric Module will help describe and improve the understanding of critical pollutant transport and advection processes that are subject to complex land-sea-breeze circulation patterns and their effect on the atmospheric abundance and composition of a variety of air pollutants. This improved understanding can be gained through the analysis of existing data and the integrated analysis of essential new monitoring activities. Through comprehensive analysis of all monitored data, linking observations with local and regional air pollutant emissions data, including specific military training

activities and land management procedures, the relative importance and potential of certain emission sources exerting stress on certain parts of MCBCL's ecosystem will be indicated.

Basic meteorological parameters, including wind speed and direction (WS, WD), barometric pressure (BP), ambient air temperature (T), relative humidity (RH), precipitation (PPT), and photo-synthetically active solar radiation (PAR) will be measured at a minimum of three locations across the Base. Currently existing stations will be upgraded and/or supplemented and if necessary relocated to cover maximal needs of all module teams including the major tributary watersheds (i.e., French and Southwest Creeks, Chadwick Bay, as well as coastal Freeman, Gillets, and Traps Creeks). Six tipping bucket rain gauges will be distributed in addition to 9 gauges currently deployed, in order to accomplishes three goals: (1) make an integrated effort to successfully characterize rainfall input to MCBCL at an appropriate temporal and spatial resolution capturing isolated events, as well as gradients with distance inland from the beach; (2) strengthen rainfall input information along the coast for the benefit of works by the Coastal Barrier and Coastal Wetlands Modules; (3) centralize this data collection effort to ensure continuity throughout DCERP.

Table 6-13 summarizes the estimated level of effort for each of the key personnel during the first four years of Phase II for the monitoring activities previously listed in **Table 6-12**. A specific list of the personnel for each monitoring activity is located within the Methods section of each monitoring activity described in Section 6.5.4 (*Atmospheric Module Monitoring Components*).

Table 6-13. Atmospheric Module's Estimated Staffing of Monitoring Activities

	Time in months/year			
Personnel	**Year 1**	**Year 2**	**Year 3**	**Year 4**
Karsten Baumann	2	1	1	1
Technician (1)	6	6	6	6

6.5.3 Benefit to MCBCL

Meteorological monitoring will provide MCBCL with an in-depth historic reference for future ecosystem management planning. Information such as temperature, wind speed and relative humidity are critical needs in forest management. Ozone, PM_{10}, and $PM_{2.5}$ monitoring data can support MCBCL operations planning to ensure it plays a positive role in helping the state maintain attainment with Federal air quality criteria pollutant standards.

6.5.4 Atmospheric Module Monitoring Components

6.5.4.1 Combined Meteorology, O_3, and fine and coarse PM

6.5.4.1.1 Objective(s)

Long-term collection and evaluation of spatially and temporally resolved meteorological data allows the establishment of a detailed climatology for the MCBCL area, including the capture of extreme events affecting hydrological processes in the estuarine and the terrestrial ecosystems (e.g., benthic response to upwelling during storm conditions, vegetation diversity change in response to increasing temperatures). Furthermore, the collection of meteorological data in combination with real-time O_3, $PM_{2.5}$ and PM_c measurements will help identify atmospheric stressors and potential critical levels during certain episodes (e.g., heat stress accompanied by high ozone and $PM_{2.5}$) causing measurable impact on certain vegetation species.

6.5.4.1.2 Relevance to the Base

In conjunction with simultaneous O_3 and PM measurements, the automated, high-resolution meteorological measurements allow the identification of internal versus external sources of dust and other primary PM sources (e.g., fires), and their respective range of impact.

6.5.4.1.3 Scale

The selected monitoring sites depicted in **Figure 6-17** cover the full vegetation diversity encountered along the hydrological gradient from the coastal area (Site 3 - Riseley Pier), mixed pocosin/loblolly pine in the Great Sandy Run Area (Site 2) to the west, and longleaf pine dominated areas to the north (Site 4). The evaluation of the combined meteorological atmospheric O_3 and PM mass measurements is synchronized with the weekly deposition measurements (Research Project Air-2). Therefore, basic correlation and frequency analyses are being reduced to weekly episodes, and incorporated into specific evaluations and interpretations of short-term wet and dry deposition episodes of special interest. Long-term trends in diurnal and seasonal patterns for the three different ecosystem locations are also evaluated on a routine basis. Chemical speciation analysis and evaluation of certain $PM_{2.5}$ and PM_{10} samples collected weekly will be part of Research Project Air-1 and closely coordinated with Research Project Air-2.

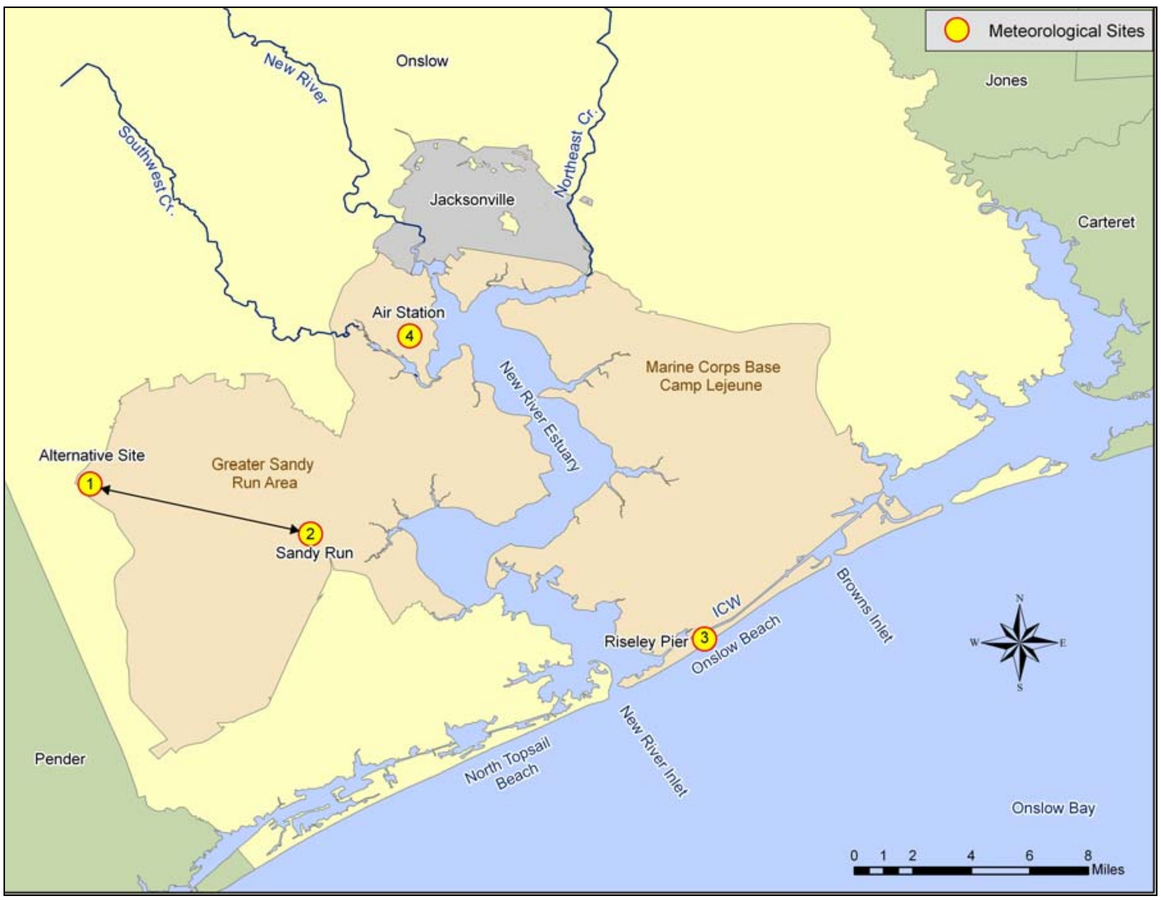


Figure 6-17. Location of current meteorological stations supplemented with continuous O_3, $PM_{2.5}$ and PM_C measurements for comprehensive analysis of atmospheric pollutants transport in support of collocated wet and dry deposition measurements.

6.5.4.1.4 Linkages within the Module and among other Modules Monitoring Components

The comprehensive meteorological and air pollutants measurements (O_3, $PM_{2.5}$, and PM_c mass) will be made in close coordination with PM chemical composition and wet/dry deposition measurements (Research Projects Air-1 and Air-2, respectively), which are integrated over weekly intervals. The PM monitoring allows simultaneous sampling of fine and coarse particle fractions onto filter substrates for chemical speciation analysis in the laboratory (as part of Air-1), and thus the generation of PM speciation data similar to EPA's Federal Reference Method (Frank, 2006). The weekly averaged composition backed by high-resolution (e.g., 5 min) wind speed, direction and $PM_{2.5}$ and PM_{10} mass concentrations, allows the determination and overlaying of wind frequency distributions with fine and coarse (from difference) PM mass giving indication of where the main mass contributions came from during a spatially captured deposition event. For example, knowing the amount of particulate N and directional distribution for a weekly average will help explain potential N deposition patterns observed and determined by Research Project Air-2; therefore, this data is indirectly beneficial to other (N sensitive) ecosystems. Information on the occurrence of locally high O_3 episodes during periods of elevated temperatures (heat stress) will provide a potential link to the senescence of O_3-sensitive plants (e.g., loblolly pine) observed on MCBCL and investigated as part of the Research Project T-1.

6.5.4.1.5 Methods

Spatial/Site Locations

The selection of sites was presented Section 6.5.2 (*Atmospheric Module Monitoring Objectives and Activities*) and are illustrated in **Figure 6-17**. (See **Appendix D** for a map depicting the preliminary assessment of military use). Although Site 3 (Riseley Pier) is located in an area of high military use, it is located directly on the beach and therefore predominantly influenced by regional maritime air masses. High wind conditions may cause also high PM_c levels that, when continuously measured, serve as useful indicators for ability to train and aid in training decisions. On the other hand, a shallow marine BL may be high in photochemical products (secondary fine PM) affecting visibility under certain summer-time conditions. Although not located directly in a highest use area, Site 4 located at the New River Air Station is downwind from sea-breeze conditions and civilian urban sources under land-breeze. Thus, this location will experience contrasting influences from internal and external sources and potential stressors. Site 3 (Greater Sandy Run Area) and Site 1 (its alternative at the western border) are located in low-use training areas and likely sensitive to more regional influences due to the lack of nearby activities. Both sites seem to be well suited to capture smoke carrying air masses from the west if the forests outside the western border are being PB managed.

Temporal Considerations

All meteorological parameters are being measured and evaluated continuously year-round in order to establish a detailed climatology for the different ecosystems on MCBCL. Like in the regulatory network, O_3 is being monitored only during the summer months, i.e., May through September. Due to its relatively high deposition velocity and surface reactivity, ambient O_3 concentrations measured in the indicated different ecosystems of the Base may vary significantly. In addition to spatial differences, temporal differences may occur superimposed on the more regional character from diurnal BL dynamics and atmospheric O_3 formation processes (Baumann et al., 2000).

More than 8 million acres of land are subject to PB every year in the Southeastern U.S. (Wade et al., 2000), with the most intense burnings and highest emissions occurring on military installations. Since PB is heavily utilized in the fire-adapted ecosystems of the Southeast, this region's ambient $PM_{2.5}$ levels are particularly sensitive to changes in land management procedures and regulations. The U.S. EPA lists PB as the 3rd largest source of primary anthropogenic $PM_{2.5}$ in the U.S., emitting 12% of the total $PM_{2.5}$ mass (U.S. EPA, 2004b). Source apportionment modeling of $PM_{2.5}$ mass concentrations from 24 Speciation

Trend Network sites suggests PB may contribute more than 30% of the annual $PM_{2.5}$ mass in the Southeastern U.S. (Lee et al., in press). Considering that the most intense burn season actually spans only half a year, i.e., from December to May, this contribution is even higher then. Our April 2004 Pilot Study at Forts Benning and Gordon, GA showed that PB significantly impacted air quality in neighboring urban communities contributing on average 38 ±6 % to the total $PM_{2.5}$ mass during and on the day following a burn (Lee et al., 2005).

While PM signatures from PB may occur only during the first half of the year, secondary atmospheric processes influencing $PM_{2.5}$ concentrations in processed continental, as well as maritime air masses are important contributors to ambient concentrations especially in mid to late summer, while local PM_c sources such as military training involving heavy all-terrain vehicles are important contributors year-round, and especially emphasized during drought conditions.

Personnel

- Senior Researcher: Karsten Baumann
- Technicians: (1)

Parameters/Variables

- Wind speed and direction (WS, WD)
- Barometric pressure (BP)
- Ambient air temperature (T)
- Relative humidity (RH)
- Photo-synthetically active radiation (PAR)
- Precipitation (PPT)
- Ozone (O_3)
- Fine particulate matter with aerodynamic diameter < 2.5 µm ($PM_{2.5}$)
- PM_{10} (PM_c from difference)

Field and Laboratory Procedures

Sampling Design and Collection

At each of the 3 dedicated comprehensive sites, analog signals from one PAR sensor, one O_3 analyzer, one $PM_{2.5}$, and one PM_{10} nephelometer are being acquired via connection to the data logger used for the meteorological parameters.

Equipment Used

The LI-190SA Quantum PAR sensor from Li-Cor will be used, which measures the Photosynthetic Photon Flux Density (PPFD) in units of quanta (photons) per unit time per unit surface area the region of the electromagnetic spectrum from 400-700 nm that is also the range of Photosynthetically Active Radiation (PAR). Colored glass filters are used to tailor the silicon photodiode response to the desired quantum response, employing an interference filter that provides a sharp cutoff at 700 nm. The sensor's µA output has to be converted to mV using a special precision resistor in order to properly acquire its signal with the existing data loggers.

O_3 is measured using a pressure and temperature compensated commercial ultraviolet absorption instrument (model TEI 49-C, Thermo Environmental Instruments, Inc., Franklin, MA), being absolutely calibrated by the known absorption coefficient of O_3 at 254 nm. The signal is generated by the difference of frequently alternating measure and reference (zero) cycles, i.e., full transfer of O_3 through versus complete removal of O_3 from the flow system.

$PM_{2.5}$ and PM_{10} mass concentrations are being measured using two of the MIE personal Data RAM (pDR-1200) sensors, highly sensitive nephelometric monitors whose (880 nm) light scattering sensing configuration have been optimized for the measurements of airborne dust, smoke, fumes, and mists in outdoor environments. By operating the pump at specific sampling flow rates, the pDR-1200 cyclone pre-separator provides precisely defined particle size cuts, i.e., here 2.5 and 10 microns. A special water vapor removal system minimizes artificially high concentrations from being recorded with the MIE (Chakrabarti et al., 2004). An integral filter holder directly downstream of the photometric sensing stage accepts 37 mm filters. The calibration constant of the pDR-1200 is simply adjusted to coincide with the filter-determined concentration. Primary gravimetric calibration of the instrument concentration readout is easily accomplished under actual field conditions by means of this integral filter.

6.5.4.1.6 Data Analysis, Products, and Outcomes

The continuously acquired ozone and PM data will be reduced to 5 minute averages, merged with the high resolution (5 min) meteorological data, and subjected to a comprehensive QA/QC procedure before being further reduced to hourly averages and entered into the DCERP data and information management system. The QA/QC screening will occur weekly and synchronized with the passive samplers' maintenance and collection (see Air-2). Part of this maintenance will be the collection of the MIE pDR-1200 weekly filter samples, which will be stored and analyzed only for cases identified by Research Projects Air-1 and Air-2. The continuous O_3, PM, and metrological data will be analyzed to characterize air quality's role in ecosystem health by providing a good understanding of atmospheric dynamics and composition, including the identification of air pollution episodes, air pollutants' atmospheric transport characteristics and potential origins,, their sources, their distribution and dispersion mechanisms in the BL above the ecosystem and their deposition processes following wet and dry deposition pathways for different seasons (e.g., growing versus dormant). In summary, the main product will be the establishment of air quality climatology for the MCBCL area for pollutants with greatest potential for acute and chronic impacts on ecosystem health.

6.5.4.2 EPA Criteria Pollutants (O_3, SO_2, $PM_{2.5}$)

6.5.4.2.1 Objectives

The purpose of this section is to describe how DCERP will utilize existing state government operated air quality monitoring stations' data to enhance an understanding of air quality in MCBCL's airshed.

Besides monitoring atmospheric BL transport processes across MCBCL, the module will also focus on the monitoring of certain air pollutants that are regulated by the U.S. EPA via national ambient air quality standards (NAAQS) mandated by the CAA for the protection of human health. Among these regulated criteria pollutants, which are ozone, sulfur dioxide, carbon monoxide, oxides of nitrogen, fine particles, and lead-containing particles (U.S. EPA, 1996), O_3 and fine particles with aerodynamic diameter smaller 2.5 microns ($PM_{2.5}$) are hardest to control, due to their indirect relationship to primary sources. O_3 is exclusively formed via secondary processes in the atmosphere, and a large fraction of ambient $PM_{2.5}$ is a product of similar secondary but heterogeneous atmospheric processes, especially in summer (Seinfeld and Pandis, 1998; Odum et al., 1997; Jang and Kamens, 2001; Limbeck et al., 2003; Claeys et al., 2004; Robinson et al., 2007.). Nitrogen oxides are being measured indirectly via passive sampler technology across the Base as part of the Research Project Air-2.

Growing demand for the military's readiness and preparedness requires more intense training and use of the available space by larger numbers of troops, entailing an expanding support structure under a growing civilian population that increasingly encroaches DoD facilities and contributes to the regional $PM_{2.5}$ burden, which is also true for Jacksonville and MCBCL. **Table 6-14** shows the criteria air pollutants monitored nearest to Jacksonville that are part of the regulatory network run by the North Carolina Division of Air Quality (NCDAQ), demonstrating the low density of monitors in the area. PM_{10} includes

a coarse fraction of particles sized between 2.5 and 10 microns, which are typically more locally confined and associated with wind blown soil and road dust or dust emitted from unique military activities, and therefore unique tracers on local scales. Hourly meteorological data are available through the network of NOAA's National Weather Service (NWS), whose sites in most cases are associated with local airports.

Table 6-14. NCDAQ monitoring in the Southern Coastal Plain nearest to MCBCL

Pollutant	County	City	Pop.	Loc Type	Mon Type	Land Use	Lat	Long	D (km) / Dir (degN) from GSRA	
$PM_{2.5}$, PM_{10}	Onslow	Jacksonville	18,312	Urban City Center	SLAMS	Residential	34.7728	-77.428	19	20
$PM_{2.5}$, O_3, SO_2	New Hanover	Castle Hayne	213	Rural	Other	Agricultural	34.3642	-77.8386	42	235
SO_2	New Hanover	Wilmington	38,678	Rural	SLAMS	Industrial	34.2684	-77.9565	58	234
$PM_{2.5}$	Duplin	Kenansville	1,157	Urban City Center	SLAMS	Residential	34.9548	-77.9608	58	306
$PM_{2.5}$, O_3	Lenoir	Kinston	11,229	Suburban	Other	Commercial	35.2315	-77.5688	69	353
$PM_{2.5}$, PM_{10}	Wayne	Goldsboro	16,372	Urban City Center	SLAMS	Residential	35.3692	-77.9939	96	326

Note: NCDAQ will discontinue their Jacksonville station on December 31, 2007 and move the PM_{10} monitor the Castle Hayne Station in New Hanover County.

6.5.4.2.2 Relevance to the Base

North Carolina monitoring station data will benefit MCBCL as it schedules training operations and plans Base management functions to ensure the Base plays a positive role in assuring good regional air ambient air quality. Monitoring station data will also enhance Base monitoring data to track the destination of PB plumes. Further, all three pollutants are documented as having detrimental effects on ecosystems components such as plant vegetation. By understanding and planning to minimize Base emissions, the Base ecosystem can be protected.

6.5.4.2.3 Scale

These sites are fixed within a sub-regional scale up to 100 km; see **Table 6-14** and **Figure 6-18**.

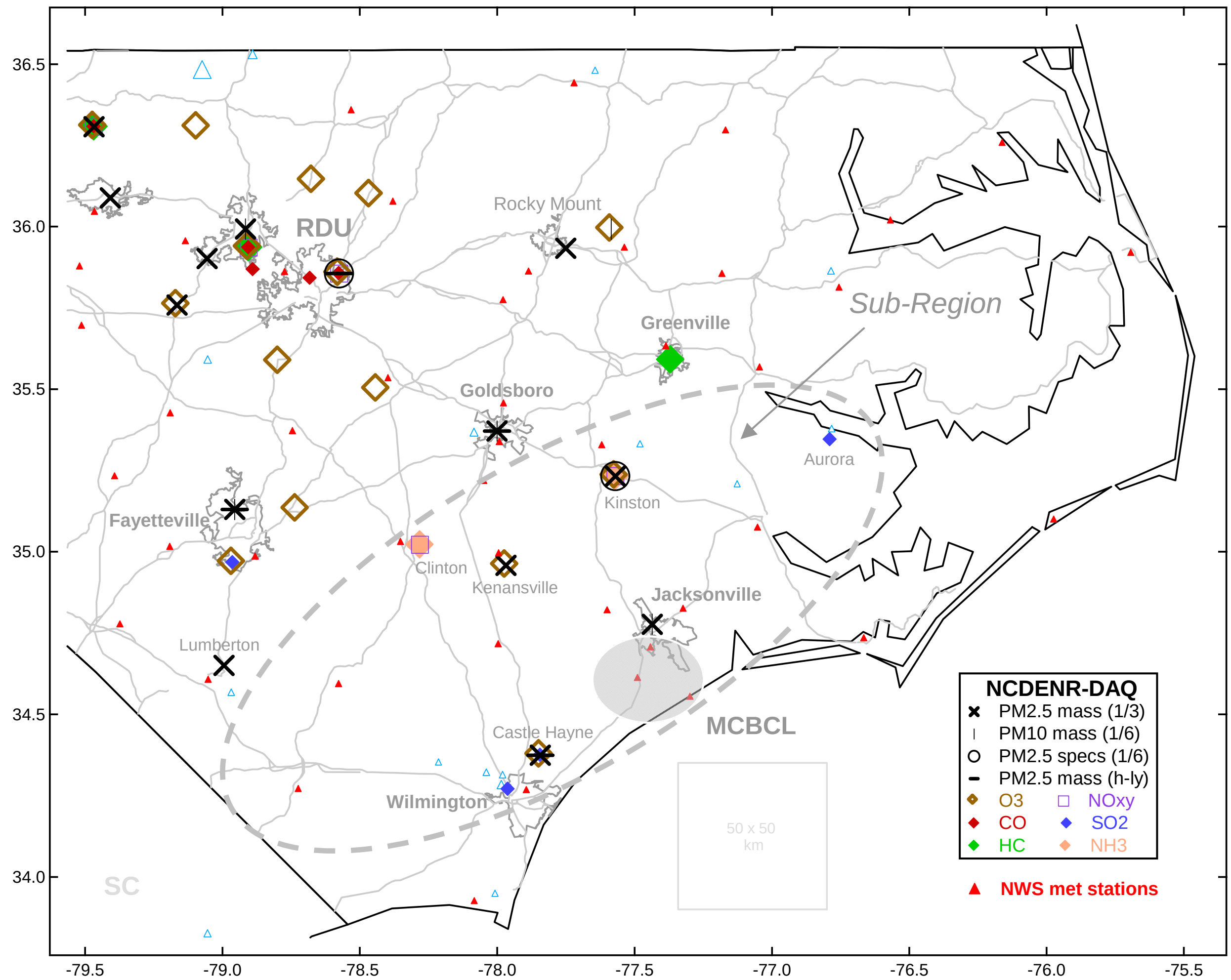


Figure 6-18. Existing regional and sub-regional criteria pollutants monitoring network

6.5.4.2.4 Linkages within the Module and among other Modules Monitoring Components

NCDAQ monitoring data evaluated and interpreted in the context of spatial and temporal distributions including seasonally refined air pollutant transport occurrences may potentially benefit all DCERP modules with current or future research projects. Local and sub-regional air pollutant records can be used in refining the fuel model development and smoke management planning focused on within Research Project Air-1, where the distinction between impacts from internal versus external PB emissions is important. Episodic $PM_{2.5}$ speciation data will provide insight into ammonium speciation for aquatic studies on the role of nitrogen deposition to nutrient sensitive waters investigated in Research Project Air-2. Information on the spatial-temporal distribution of PM species mass concentration (wind roses) for certain weekly wet and dry deposition episodes, e.g., will support those investigations. Lastly, the temporal and spatial occurrence of high O_3 and heat stress episodes will provide a potential link to the spatial extent of the senescence of O_3-sensitive plants (e.g., loblolly pine) observed and investigated as part of Research Project T-1.

6.5.4.2.5 Methods

Spatial/Site Locations

Table 6-14 and **Figure 6-18** identify the locations of each NCDAQ-operated monitoring station. Each station is located outside the confines of MCBCL; providing a regional context of the Base's air quality.

Temporal Considerations

The NCDAQ data will be used in support of the routine evaluation of the data collected on the Base. Sampling frequencies vary with the parameter (e.g., SO_2 and O_3 data are reported hourly, daily average $PM_{2.5}$ and PM_{10} mass are reported every 3rd or 6th day, respectively, with $PM_{2.5}$ speciation data from Kinston available every 6th day as well); however, the data collected provides a reliable, long-term temporal scale for Base analyses.

Personnel

- Senior Researcher: Karsten Baumann

Parameters/Variables

- Ozone
- $PM_{2.5}$
- Sulfur dioxide

Field and Laboratory Procedures

Sampling Design and Collection

Regional (eastern North Carolina) field monitors are operated by the State of North Carolina. Sampling design information and equipment used can be obtained from NCDAQ.

6.5.4.2.6 Data Analysis, Products, and Outcomes

Data will be entered into the DCERP data and information management system. Analysis may include verification or comparison with onsite monitoring data, trends analysis, and modeling studies performed within the Atmospheric Module's Research Projects (Air-1 and Air-2). The combined evaluation of the local (MCBCL) measurements with the sub-regional (off-Base) regulatory network data will put MCBCL's air quality climatology in the more regional context, yielding the following outcomes:

- Establish temporal trends of important air pollutants across MCBCL ecosystem.
- Identify and understand certain MCBCL deviations from more regional air quality trends.
- Identify and understand temporal and spatial sensitivities of PB conduct.
- Identify parameters, locations, and frequencies to be monitored long term.

6.6 Adapting the Baseline Monitoring Plan

Although it is intended for each of the baseline monitoring activities described in this plan to continue for a minimum of 5–10 years, it is understood that changes, or adaptation, of the monitoring activities may occur during Phase II of DCERP. Adaptation of this DCERP Baseline Monitoring Plan may result in the modification of the types of samples being taken, the frequency and/or spatial distribution of sampling locations or, in some cases, the sampling methodologies. It is also possible that some components may be completely removed from the Monitoring Plan if it is determined that they are not providing the intended outcomes or the data necessary to support the research efforts. The results from the monitoring efforts will be evaluated on an annual basis to determine if the desired outcomes are being achieved in a timely and cost-effective manner and if the DCERP Baseline Monitoring and Research plans need to be adapted to achieve greater benefit to DCERP.

7.0 Data Management Module

The backbone of the DCERP research, modeling, and management tools will be environmental data collected throughout the duration of the program. The types and volumes of baseline data that currently exist (historical data) and that will be collected during the DCERP baseline monitoring and research program are extensive. It is essential that a comprehensive data management plan be developed and implemented to ensure that these data are accessible to researchers across modules. General categories of data to be collected and managed include the following: structure data (e.g., monitoring and research data), unstructured data (e.g., Web sites, reports, and publications), and spatial data (e.g., vector and raster).

The Data Management Module will develop a data and information management system to support the other DCERP modules. MARDIS will store and manage the data collected by the DCERP module teams, and the Document Database will provide for simple retrieval unstructured data, such as documents. General categories of data to be collected and managed include the following:

- *Structured Data*: Tabular environmental monitoring data from each module having defined content and structure that will be managed in a standard Relational Database Management System (RDBMS)
- *Non-spatial* and *unstructured data*: Spreadsheets, SAS files, word processing documents, Web sites, reports, and research publications that provide valuable information for DCERP, but that are not in a structured format suitable for an RDBMS. These files will be managed in the Document Database and will be searchable via explicit metadata that describe the content of each file. Rather than storing and managing raw data (such as monitoring data), this database will manage documents.
- *Spatial data (vector and raster*): Where possible and appropriate, geospatial data will be stored and managed in geospatial databases so that they are accessible via similar mechanisms as structured data. In some cases, however, these data may need to be stored outside a geospatial database and managed at a file-system level.

The DCERP Strategic Plan calls for the development of a data repository to provide the tools and structure to manage these data. Based on our understanding of the needs of the project, the concepts implied by the term “data repository” should be expanded to include concepts of overall data and information management systems. The models and tools currently included as outcomes for selected research projects will be housed in the data and information management system. Although the data management plan does not currently include the development of an overall decision-support system, the data and information management system will be designed to enable the development and use of an overall decision-support system in the future. For example, the technology environments proposed for the data and information management system should enable future use of technologies, such as Web-based tools, Web services, and other interoperable technologies.

7.1 Data and Information Management System

7.1.1 MARDIS: Structured Data

The Data Management Module will work with the Module Team Leaders to define the database structure of MARDIS using RDBMS technologies. This will involve on-site or teleconference meetings so that staff who are designing MARDIS understand the type, content, volume, and resolution of the research and monitoring data being collected. If possible, Module Team Leaders should provide sample data tables to help in communicating content and format. Standards for specifying the locations of monitoring stations will also be developed to ensure that the locations of each monitoring datum are correctly assigned to an accurate location. Use of GPS devices to record the location of monitoring devices will be encouraged—

especially for any ad hoc or event-driven monitoring where new stations are being set up or existing stations are temporarily being moved.

In addition, the Data Management Module will work with the Module Team Leaders and their staff to define appropriate formats for monitoring and research data to be uploaded into MARDIS. For each type of monitoring data to be collected, a standard data delivery format will be specified that will be used to upload these periodic monitoring datasets to MARDIS. Different upload schedules will be defined for different types of monitoring (i.e., different equipment or collection schedules will determine period intervals between each upload). After performing quality checks on their data, the research groups will convert the data to the agreed-upon upload formats and upload the data to MARDIS. MARDIS will include selected data checks to ensure the basic accuracy and consistency of the upload process and that the data being uploaded conform to the specified data formats. Basic quality checks will also be made to ensure that, where possible, data values that are invalid or out of range are detected prior to loading. MARDIS will include a staging area where data will be uploaded and checked. After the data checks are completed successfully, the data will be appended into the core database. This process will ensure that only the highest-quality data are maintained in MARDIS. The uploaded data will be stored in structured relational database tables that will hold these long-term data so that, in the future, researchers from any module can access and download different types of data for any time period.

Research groups will be responsible for processing raw monitoring data results (e.g., laboratory results) into agreed-upon formats for upload. In addition, research groups will be responsible for conducting the QA/QC procedures for data they are collecting. The MARDIS upload mechanism can provide some data checks to ensure that data formats are correct, but the mechanism cannot do a complete QA/QC on raw data. All monitoring and research procedures (including both field and laboratory equipment methods) will be developed by the individual investigators as standard operating procedures (SOPs), and these SOPs will be archived in MARDIS. Researchers will frequently perform data analyses, data synthesis, and data integration on monitoring data, thereby generating derivative data files and products. These analytical products may be held in the form of spreadsheets, documents, tables, or other relatively unstructured formats that are suitable for research purposes. Although these data products are not in structured formats and will not be loadable into standardized database tables, they should still be submitted so that they can be documented and managed. The Document Database design will provide a Web-based interface to allow researchers to upload the documents and describe their contents using standard ecological metadata definitions (see Section 6.1.2, *Monitoring Objectives and Activites*). The Document Database will also provide a mechanism for researchers to search the repository for these unstructured files to find documents that may contain data of interest.

Historical data from non-DCERP monitoring sources will be assessed to determine whether the data should be translated and uploaded to MARDIS or should remain in their native format and either be stored in the Document Database (most likely if the legacy data is not being changed or updated) or, if pointers to the locations of these external data sources exist, be included in MARDIS.

MARDIS will include the development of Web-based query tools to enable researchers to find and download data of interest and develop selected data summary tools to perform basic statistical analyses of data (i.e., if researchers commonly use mean monthly temperatures in their research rather than daily temperatures, MARDIS could include tools that would automatically calculate mean monthly temperature data and manage these derivative data). In addition, MARDIS will enable the development of Web-based models or other analysis tools that will be driven by data from the repository.

7.1.2 Document Database: Unstructured Data

The data and information management system will also house and manage non-spatial, unstructured, or derivative data. Rather than present the data in structured database formats, the Document Database will

provide easy-to-use formats (e.g., spreadsheets, SAS databases, tables) for use by the module teams. The data and information management system will include a tool for researchers to upload these non-structured data tables and explicit metadata into a Document Database. The Document Database will provide query functions to help researchers understand the content of the documents stored and locate documents or files that contain data of value to their research.

7.1.3 Geospatial Data

The data and information management system will explicitly include the management of geospatial data. The specific structures and formats chosen will be based on requirements and needs analysis carried out with research modules and MCBCL staff. It is presumed, however, that geospatial databases will be developed that will enable the use of geospatial data standards, Web-based mapping, and Web-based geospatial data services to allow the design and development of decision-support systems in the future that will run against geospatial data in the data repository.

7.1.4 Web Sites

The DCERP Collaborative Web site is a place where DCERP Team members can share administrative planning documents, reports of activities, and other information of interest to their group and other DCERP Team members. It also includes a calendar for scheduling and managing field monitoring and research activities. This site is password protected and can only be viewed by the DCERP Team.

The DCERP public Web site (http://dcerp.rti.org/) provides the general public with information about the program, including the mission statement for DCERP, as well as the background, objectives, approach, and benefits to MCBCL. Only documents that have been reviewed and approved by the researchers, MCBCL, and SERDP will be posted on the public Web site. The public Web site also contains contact information for SERDP staff, the DCERP PM, the DCERP OSC, the DCERP PI, and all DCERP Module Team members, as well as links to affiliated organizations.

7.2 Data Reporting

Standard reporting applications will be implemented for the data and information management system to develop reports to document the system's contents. Reports will include lists of all files in the system, the number of records in files, and perhaps charts and graphs that indicate how records have been added each month or quarter. A final report will be prepared indicating the final structure and content of the data and information management system.

7.3 Models and Management Tools

The ultimate goal of DCERP is to develop tools to enable MCBCL managers to identify adaptive, ecosystem-based management approaches, such as models for forecasting the impacts of military activities and other stressors or indicators for assessing healthy, transitional, or degraded conditions. The scale and complexity of these tools will depend on the needs of MCBCL and the level of funding available to the program. Currently, several of the proposed research projects include tools and models as project outcomes, which will enable MCBCL managers to make informed decisions to support their long-term goals of military training and preparedness.

As the DCERP ecosystem research and monitoring strategy is implemented, the need to develop analytical workflow systems and management tools to automate the processing of raw monitoring data into useful management information will increase. The RTI DCERP Team will work with MCBCL staff to identify and prioritize opportunities for the development of automated workflow processes, integrated models, and new management tools. Because this process will necessarily be driven by emerging end-user needs at MCBCL and the data products and models yet to be developed by DCERP, it is difficult to

directly anticipate and prioritize the specific models and tools that will be needed at this time. As DCERP evolves and matures, planning for the future development and implementation of these end-user tools will require a focused planning and evaluation effort to identify and prioritize this work. These efforts will be conducted in close coordination with the development of the DCERP data and information management systems, and outcomes of these efforts will be used to refine the architecture of the system. Full implementation of the automated data analysis systems, integrated models, and decision-support tools identified by this process will then be proposed for funding through the DCERP effort or a separate funding arrangement, if appropriate.

8.0 Quality Assurance

RTI and its subcontractors will perform and document QA/QC procedures to ensure the technical accuracy and scientific defensibility of work conducted under this DCERP contract. Quality assurance is a key component of RTI's work processes; therefore, RTI and each subcontractor will prepare (as necessary and appropriate) SOPs, data collection plans, software requirements documents, database design documents, and model verification test plans for their own work. These documents will clearly describe the measures taken to ensure adequate QA and QC. Each subcontractor will also develop SOPs or employ existing SOPs to cover key routine activities, including environmental data collection and analysis, model development, data management, and data validation. RTI will post these SOPs and other QA planning documents to MARDIS where they will be archived with the products and data they support.

RTI and its subcontractors will develop, implement, and document QC checks to ensure the appropriateness and accuracy of the conceptual approach, methodologies, data, algorithms, models, and the documentation of data and methods used in and the results of the analyses. RTI and its subcontractors will use a variety of QC techniques to identify potential sources of error during this work. Each contractor will confirm the reasonableness of environmental data collected under this project and check hand-entered data for accurate transcription (of values and units). Calculation checks will also be performed. Documentation will be written in a clear, transparent manner and will be concise, complete, and editorially correct.

9.0 Transition Monitoring Program to MCBCL

The DCERP baseline monitoring program was designed with the goal of transitioning a scaled-down version of the program to MCBCL at the end of the project (or sooner if the Base so desired). MARDIS will standardize the storage of monitoring data, and the DCERP Web site will be a venue for access for the research team and the DoD community, including MCBCL natural resources managers. Results from the monitoring activities will be summarized in quarterly and annual reports and submitted to SERDP and MCBCL. These results will help identify key indicators and ecosystem components that need to be continuously monitored as the core elements of the baseline monitoring program. In addition, when requested, the RTI DCERP Team will have progress meetings with MCBCL to facilitate the transfer of knowledge throughout the duration of the program.

Six months prior to the completion of DCERP, the RTI DCERP Team will work with Base personnel to begin transitioning the baseline monitoring plan to MCBCL. This transition will involve hands-on training for MCBCL staff in the use of the equipment, including the transfer of all SOPs and an overview of data analysis procedures and reporting. Ultimately, all monitoring activities and data collected as part of DCERP will be transitioned to the Base at the completion of the program.

10.0 Measurements of Success

The successful implementation of DCERP will foster a greater understanding of the biologically diverse aquatic/estuarine, coastal wetland, coastal barrier, and terrestrial ecosystems of MCBCL; the Base's air quality; and the interactions of these systems with military training activities. This understanding will aid in the long-term management and sustainability of MCBCL ecosystems, which will enhance and maintain MCBCL's military mission. Information and data resulting from the DCERP research and monitoring efforts will increase the ability of resource managers to perform assessments and implement appropriate management responses to potential environmental impacts arising from military activities or natural disturbance events. In addition, DCERP's monitoring metrics and techniques likely will be transferable to other DoD installations in ecologically similar settings.

Measurement of DCERP's success will come from assessing whether the desired outcomes are achieved, and whether the outcomes are produced in a timely manner. The outcomes defined for DCERP can be grouped into two main categories:

- Programmatic—Includes administrative requirements such as delivering required documents on schedule and on budget, ensuring that the project Web site is developed and functioning, meeting SERDP quarterly and annual reporting requirements, and providing timely and effective feedback to MCBCL and outreach to stakeholders. The DCERP Strategic Plan provides a list and delivery schedule for currently anticipated programmatic products/outcomes.
- Project specific—Includes those outcomes identified in this DCERP Baseline Monitoring Plan, as well as those associated with the research projects presented in the DCERP Research Plan. These outcomes provide information to address environmental issues that are currently impacting Base operations. Other monitoring efforts were designed to provide outcomes relevant to issues that are currently known and that are anticipated to impact Base operations in the next 3–5 years. In addition, the majority of DCERP research and monitoring activities will provide information necessary to gain a complete understanding of ecosystem functions, which will better prepare Base managers to address future environmental issues.

Specific programmatic and overarching, strategic outcomes are included in the DCERP Strategic Plan (RTI, 2007a). Project-specific outcomes associated with the monitoring activities for the individual modules are provided in **Table 10-1**.

Table 10-1. Important Outcomes of Module-Specific Monitoring Activities

Monitoring Activity	Aquatic/Estuarine Module Outcomes	Completion Date
New River monitoring	River discharge and tide data will be used for placing nutrient and sediment samples in the appropriate hydrologic and tidal context.	2010; ongoing
	To distinguish upstream inputs from Base sources, river discharge, nutrient, and sediment data will be used in the hydrodynamic models developed in Research Projects CB-1 and CB-2 and the Watershed Simulation Models (WSMs) and Estuarine Simulation Model (ESM) developed in Research Projects AE-1, AE-2, and AE-3 to compute the daily loadings of nutrients and sediment being transported into the estuary from upstream sources.	2010; ongoing
Tidal creek monitoring	Water velocity, nutrient, and suspended particle data will be used to estimate loadings of nutrients and sediments. Nutrient and sediment loading rates from creeks will be used in hydrodynamic models developed in Research Projects CB-1 and CB-2 and the WSMs and ESM developed in Research Projects AE-1, AE-2, and AE-3.	2011

Monitoring Activity	Aquatic/Estuarine Module Outcomes	Completion Date
	Suspended sediment loads will be used in the Marsh Elevation Model (MEM2) developed in Research Project CW-1 because these loading represent an importation source for marsh accretion. Thresholds for minimum sediment loading required to support MCBCL marsh accretion will be assessed.	2011
NRE - Water column chemistry	Water velocity and nutrient and particle suspensions will be used to estimate flux and loading of nutrients and sediments to the NRE. Nutrient and sediment loading rates will be applicable to the WSMs and ESM developed in Research Projects AE-1, AE-2, and AE-3.	2011
	Suspended sediment loads will be used in the MEM2 developed in Research Project CW-1 because these loadings represent an important source for marsh accretion.	2011
NRE - Water column primary producers	Maps of primary production, phytoplankton biomass, and harmful algal blooms (HABs) will be developed.	2008; ongoing
	The space-time relationships between nutrient, sediment, and other contaminant inputs, and phytoplankton production responses under variable hydrologic conditions will be examined.	2008; ongoing
	Chlorophyll *a* and associated results will be used in the ESM being constructed in Research Project AE-3 and the Bayesian Probabilistic Model being developed in Research Project AE-1.	2011
	Phytoplankton results will be formatted to serve as calibration and verification data for remote-sensing efforts aimed at scaling up production and HAB dynamics to the entire estuary.	2010; ongoing
	Indicators for chlorophyll *a* and associated physical-chemical parameters will be used to identify NRE sites with healthy, transitional, and poor condition. These indicators will identify areas of the NRE that meet North Carolina and EPA water quality standards for estuaries.	2008; ongoing

Monitoring Activity	Coastal Wetlands Module Outcomes	Completion Date
Land cover and shoreline erosion	Distribution of coastal wetlands along salinity, wave exposure, and elevation gradients will be determined, and this data will be used in ecosystem models to predict how changes in environmental variables, sea-level rise, or disturbance may alter distribution of NRE coastal wetlands.	2011
	Maps and GIS layers of marsh distribution and species composition, elevations, shoreline delineation, and wave energy will be developed to identify shoreline areas vulnerable to erosion.	2008; ongoing
Marsh surface elevation	Spatial and temporal variation in marsh elevation change and accretion rates will be incorporated into a MEM2, developed in Research Project CW-1,that will forecast coastal wetland response to sea-level rise and nutrient additions, and a Shoreline Erosion Model (NRESE developed in Research Project CW-2) that forecasts NRE shoreline erosion	June 2011
	Water level data will be used in combination with marsh elevation distribution to calculate flooding times (hydroperiod) for coastal wetlands.	September 2009; ongoing
Marsh ground water and nutrients	Water/nutrient fluxes will be estimated first by using a groundwater flow model calibrated with hydraulic head, hydraulic conductivity, and salinity. Then, a Coupled Water and Salt Mass Balance Model will be constructed to independently quantify all components of the marsh water budget (developed in Research Project CW-3).	January 2010
	The coastal wetland piezometer networks will determine water flowpath direction, velocity, flux rates, and water-residence times.	December 2008

Monitoring Activity	Coastal Wetlands Module Outcomes	Completion Date
	The water budget of the marsh subsurface depends on tidal and shallow groundwater-forcing functions. The magnitude of these forcing functions changes seasonally with the rise and fall of the water table and tidal amplitude. Nutrient inventory changes primarily seasonally in response to temperature. The flowpath direction, velocity, fluxes, and residence times for water and nutrients can be correlated to water table height, tidal range, and temperature. Collectively these parameters should serve as a metrics or tool for the future assessment of seasonal marsh connectivity to, and moderation of nutrient loads from, the adjacent watershed and estuary.	January 2010

Monitoring Activity	Coastal Barrier Module Outcomes	Completion Date
Hydro-dynamics (Oceano-graphic data)	Data will be analyzed using traditional time-series analysis, as well as wavelet analysis techniques (Fourier Transform Analysis), to decipher key tidal frequencies, their amplitudes, and their contributions to the variability of flow within this system. This information will be used in the ADvanced CIRculation (ADCIRC) model developed by the Coastal Barrier Module's research projects.	June 2010
Hydro-dynamics and nearshore bathymetry	Geo-rectified maps of the shoreline and nearshore sandbars will be developed using mobile radar data. These data will facilitate an understanding of sediment transport pathways and recovery from storms or military operations on Onslow Beach.	June 2009; ongoing
Shoreface bathymetry	Shoreface bathymetry maps will be developed in geo-rectified formats using high-density, 3-D point data. These maps will illustrate sediment volume changes through time, providing an understanding of sediment-transport processes. The bathymetry data will be used in the Short-term Barrier Evolution and Long-term Barrier Evolution models being developed in Research Projects CW-1 and CW-2, respectively.	June 2009; ongoing
Barrier morphology	Barrier topography maps will be developed in geo-rectified formats using high-density, 3-D point data. Maps showing sediment-volume changes through time will be produced, indicating areas vulnerable to storm surge and sea-level rise.	June 2009; ongoing
	Maps showing changes in the position of the foreshore/backshore and backshore/dune transitions and the aerial extent of these environments will be produced.	June 2009; ongoing
Sediment texture	A summary report will be developed that provides graphs of sediment texture (individual weight percent versus diameter) for each sediment sample. Maps showing changes in sediment texture through time will be developed. Changes in sediment texture will be used as an indicator of habitat quality and extent. For example, foraging success, turtle-nesting site locations, and sediment transport are all controlled, in part, by sediment texture.	June 2009; ongoing
Benthic invertebrates	The mean density and abundance of benthic invertebrates along the barrier will be quantified and evaluated with respect to wave energy and sediment transport, sediment composition, and shorebird feeding and nesting success. A report will be developed that summarizes these results.	June 2011
	A reliable index of habitat value for foraging shorebirds and surf fishes that is based upon the biomass of key prey taxa of benthic macroinvertebrates will be developed.	June 2011
Surf fish and sea turtles	Data on abundances of surf fishes will be compiled as means of each species per site. Effects of disturbance levels along the beach on surf fish abundance (total and by species) will be determined and summarized in a report.	June 2011
	An evaluation of the factors determining whether site selection for sea turtle egg laying and hatching success varies significantly with the presence of erosion scarps, foredunes of various elevations, sediment grain size, shell content of sediments, and sediment hardness will be conducted, with the results presented in a summary report.	June 2011

Monitoring Activity	Coastal Barrier Module Outcomes	Completion Date
	An interdisciplinary evaluation of the site-specific need for beach nourishment based on shoreline erosion rates will be presented in a report. Guidance on the range of sediment types that preserve habitat value for nesting sea turtles and feeding and nesting of key shorebirds and guidance on whether to restore the dune line during beach nourishment will also be presented in a report.	June 2011
Shorebirds and seabirds	Data on bird abundance and reproductive indices will be analyzed and linked to the various ecosystem components of the coastal barrier. A summary report that presents these analyses will be prepared.	June 2011

Monitoring Activity	Terrestrial Module Outcomes	Completion Date
Plant species composition, diversity, and distribution	Tree density and volume, herbaceous cover and diversity, and fuels will be determined for each plot using the standard summary statistical metrics. Compositional variation among individual plots will be assessed using PC-ORD software.	June 2010
	Spatial and temporal vegetation change data (e.g., composition, diversity, fuel loads) will be evaluated using Mantel and partial Mantel models (Research Project T-1). A detailed model relating species diversity and surface fuels to site conditions and disturbance history will be developed.	June 2010
	Fuel load measures will be used in the U.S. Forest Service National Fire Danger Rating System (NFDRS) model (Research Project T-1) to assess plot and area fire risk.	June 2010
Assessment of land use/land cover change	GIS datalayers of historic (early 1980s) and existing landcover, topographic LIDAR, Landsat, and hydrography NHD+ data will be compiled.	June 2008
	Integration of military use data with land-cover change analysis will be conducted to provide use statistics for micro watersheds.	June 2008
	A spatially explicit map and dataset of land-use change for the New River watershed will be developed using historic and current Landsat data and updated as needed.	June 2009; ongoing
	A land cover change report will be develop encompassing the initial 4-year period of DCERP.	June 2011

Monitoring Activity	Atmospheric Module	Completion Date
Air quality	A reliable, temporally, and spatially highly resolved set of air quality and meteorological data for both the local MCBCL area and surrounding area (within 100 km radius) will be developed.	June 2009

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Appendix A

Introduction to Military Operations
Marine Corps Base Camp Lejeune

Background

Marine Corps Base Camp Lejeune (MCBCL) is the U. S. Marine Corps' (USMC's) largest amphibious training base and is home to 47,000 Marines and Sailors (U.S. Navy personnel)— the largest single concentration of Marines in the world. MCBCL encompasses approximately 159,000 acres, including the onshore, nearshore, and surf areas in and adjacent to the Atlantic Ocean and the New River. The installation includes the following:

- 11 nautical miles (nm) of ocean coastline, including 1.4 nm of amphibious landing beach, 1.6 nm of recreational beach, and 4 nm of buffer/impact-area beach
- 246 square miles (mi^2) of land area, with more than 101,000 acres of usable training area
- 74 live fire ranges and training facilities
- A Military Operations in Urban Terrain (MOUT) Facility with 31 buildings; an Urban Training Facility with 70 buildings; and a Combat Town with 14 buildings
- Shallow ocean areas (less than 100 fathoms) and the New River
- 200 mi^2 of Special Use Airspace, restricted for military use from sea level to 17,999 feet
- 3 impact areas that support munitions from 5.56 mm to 155 mm, delivered by direct fire, indirect fire, Fixed Wing and Rotary Wing aircraft, and Naval Gunfire
- 48 Tactical Landing Zones; 12 Ground and 5 Water Drop Zones; 34 Gun Positions; 8 Mortar Positions; and 12 Observation Posts
- A landing helicopter assault (LHA) deck for helicopter pilot training and an air field seizure facility with a mock airport and two runways.

To train and maintain combat-ready troops for expeditionary deployment, MCBCL must provide a variety of environmental conditions and ecosystems in which to train Marines. This objective must be met in a way that provides for sustainable, healthy ecosystems; complies with all applicable environmental laws and regulations; and provides for no net loss in the capability of military installation lands to support the military mission of the installation.

MCBCL Military Mission and Operations

The USMC mission is national defense, and the mission of MCBCL is to train and maintain combat-ready units for expeditionary deployment anywhere in the world. The MCBCL's tenants include the 2nd Marine Division, 2nd Marine Logistics Group, II Marine Expeditionary Force, United States Coast Guard (USCG), and U.S. Naval Hospital Camp Lejeune.

To accomplish the national security mission, Marines, Sailors, and USCG personnel must be trained in all requirements for responding to national security threats. Training activities include, but are not limited to, amphibious/expeditionary operations, employment of combined arms, use of tracked vehicles, infantry and vehicle maneuvers, artillery and small-arms firing, aerial weapons delivery, engineer-support operations, logistics support, field combat service support, communications, airlift support for troops and weapons, equipment maintenance and field medical treatment, and harbor/port security. MCBCL units train with some of the most modern and sophisticated weapon systems and equipment available to the U.S. military. This technology is constantly evolving and oftentimes requires large land areas for training.

MCBCL provides support and services that enhance the operational readiness and the quality of life of the operating forces and MCBCL community. MCBCL provides deployment support to warfighting commands, such as the 22nd, 24th, and 26th Marine Expeditionary Units; the 2nd Marine Expeditionary Brigade; the II Marine Expeditionary Force; and the USMC Forces Special Operations Command. MCBCL is also responsible for providing resident formal school training to approximately 39,000 Marines annually through the Marines of School of Infantry East, Sniper School, Marine Corps Combat

Service Support Schools, Marine Corps Engineer School, Field Medical Support School, and the USCG Special Mission Training Center.

Training Environments

MCBCL has more than 101,000 acres and 97 training areas subdivided into the following:

- Training maneuver areas (located near cantonment areas) that are used for ground training, including bivouacking and foot travel
- Tactical maneuver areas that support both mechanized and ground training
- Special training areas, including Combat Town and MOUT facilities
- Amphibious training.

The following sections provide a description of some of the assets at MCBCL.

Training Maneuver Areas

MCBCL has 82 designated training maneuver areas in and around the live fire ranges and impact areas. Each training area is designated alphabetically from “BC” to “SW.” Seventy-seven of the 82 training areas are designated as tactical maneuver areas, and 4 areas are designated for amphibious exercise support and beach training.

Impact Areas

There are three main impact areas in MCBCL: G-10, K-2, and BT-3/N-1. Impact areas are dudded areas, i.e., places where high explosives are used and if they do not explode on impact, they do not dud (things that should, but do not, explode). Unexploded ordnance is present in impact areas, and access is strictly controlled.

G-10 Impact Area and Ranges

G-10, located east of the New River, supports air-to-ground operations, helicopter gunnery exercises, mortar fires, field artillery indirect fires, infantry weapons, and infantry rocket and missile live-fire evolutions. Laser designators can be used within the G-10 Impact Area. Seven ranges encircle the G-10 Impact Area: G-3, G-3A, G-5, G-6 Company Battle Course, G-8, and G-9. Each range can support multiple direct- and indirect-fire weapon systems.

K-2 Impact Area and Ranges

K-2, located on the western banks of the New River, supports infantry weapons training, mortar fires, field artillery indirect fires, and infantry rocket training. The K-2 Impact Area has 23 live-fire ranges oriented around its perimeter. Each range can support multiple direct- and indirect-fire weapon systems. These ranges are oriented to support infantry weapon systems and infantry tactics.

BT-3/N-1 Impact Area

BT-3/N-1 is located on the southeast corner of MCBCL, with a 168-degree direction of fire (seaward). This impact area is a live-fire range that can support air-to-ground weapons, ground-to-air Stinger and Avenger fires, field artillery direct fires, riverine training, helicopter gunnery exercises, and machine gun familiarization training. The H Range (the Riverine Assault and Waterborne Gunnery Range) is located within the boundaries of BT-3/N-1.

Engineer Training Areas (ETAs)

There are eight ETAs on MCBCL, with the primary function to provide operational engineering units and the Marine Corps Engineer School with facilities to conduct engineer demolition training. Alternative uses of the ETAs are as an infiltration course at ETA- 1; as a mechanized assault course and breaching operations range at ETA-2; for execution of live-fire breaching exercises at ETA-4; and as a close-quarters battle area and MOUT breaching house at ETA-5A. ETA-6 is not a live-fire ETA and has been converted to a Combat Vehicle Operators Training Confidence Course.

Military Operations in Urban Terrain (MOUT) Facility and MOUT Assault Courses (MACs)

The MOUT Facility is a 31-building facility focused on training for combat in urban areas. The new Urban Training Facility, located nearby, has 69 buildings (including 5 live-fire houses). The Urban Training Facility is laid out to resemble a Middle Eastern village and includes a market area, tunnels, walls, and courtyards, with a firm base and Vehicle Check Point nearby.

Greater Sandy Run Area (GSRA) Ranges.

The Greater Sandy Run Area (GSRA) ranges are located on the western side of MCBCL. These ranges primarily support tank, Light Armored Vehicle (LAV), Amphibious Assault Vehicle (AAV), and Infantry platoon training.

Stone Bay Ranges

Stone Bay has three 50-target known distance rifle ranges, two pistol ranges, and a 1,000-yard sniper range. The Weapons Training Battalion maintains and operates these pistol and rifle ranges for annual marksmanship qualification training and familiarization firing. There are 8 additional ranges at Stone Bay or within the Special Operations Training Ground compound, including Dodge City; 1-story and 3-story shoot houses; breacher facilities; climbing walls/towers; and a multipurpose range.

Live-Fire Ranges

When shooting explosive materials, all firing is done into impact areas; however, when shooting into live-fire ranges, inert munitions (i.e., all explosive material has been removed) are utilized.

Observation Posts (OPs)

There are 12 Observation Posts (OPs) at MCBCL. These OPs are used for observation of live-fire and laser operations at each of the impact areas, amphibious operations on the beach area, and live-fire and maneuver events at the GSRA and on ranges L-5 and F-5.

Helicopter Landing Zones (HLZ)

MCBCL has two types of HLZs: Tactical Landing Zones (TLZs) and Administrative Landing Zones (ALZs). There are 48 TLZs within MCBCL's boundaries (named after birds) and 24 numerically identified ALZs. The TLZs are scheduled for heliborne operations, rappelling, fast rope, and Special Purpose Insertion Extraction rig training.

Drop Zones (DZ)

Drop Zones (DZs) are TLZs designated for parachute operations. MCBCL has 12 DZs and 5 additional Water Drop Zones (WDZs).

Gun Positions (GPs)

There are 34 Gun Positions (GPs) used for artillery training, and the majority of GPs on MCBCL double as LZs.

Onslow Beach

MCBCL also maintains 11 nm of Onslow Beach to support amphibious operations. Operations at the beach range from daily exercises by the 2nd Amphibious Assault Battalion and Joint Armed Services training to periodic, large-scale training, such as the quarterly Capability Exercises that include explosives on the beach, inland artillery fire, and 3 Landing Craft Air Cushion (LCAC) and 10 to 12 AAV landings.

New River

The USMC has a mission requirement to conduct combat and combat-support operations in shallow-water and riverine environments. Training on the New River includes activities by two USMC commands and one USCG unit. 2nd MARDIV supports II MEF with 17 Riverine Assault Craft (RAC), 65 Rigid Raider Craft (RRC), and 100 Combat Rubber Raider Craft (CRRC). These boats include jet and propeller-driven boats designed for high-speed military operations in shallow-water and riverine environments.

Day and night training exercises include insertion and extraction of personnel, re-supply and refuel between vessels, waterborne refueling, formation traveling, and live-fire of medium and heavy machine guns. Current exercises occur at a rate of approximately 635 per year and are expected to increase to 830 per year.

The 8th Engineer Support Battalion uses boats to transport and build floating bridges and has 21 Bridge Erection Boats (BEB) in their inventory. BEBs are 27 feet long and are driven by twin hydro-jet propulsion units powered by two diesel engines. These boats have traditionally been used to transport and build expeditionary-type bridging and to ferry equipment across areas too wide to bridge. The recent acquisition of GSRA has also required an increase in military training traffic on the New River. Seventy-ton M1A1 tanks belonging to the 2nd Tank Battalion are now ferried across the river to reach training areas and firing ranges in GSRA.

Types/Groups of Military Training Operations

All Marines on MCBCL can be divided into four major groups: (1) logistics, (2) command, (3) aviation, and (4) ground combat units.

Logistics and Command Troops

Logistics and command troops are generally restricted to well-established, cleared, disturbed areas, such as TLZs, DZs, and GPs. There are 48 TLZs within MCBCL's boundaries: 12 DZs, and 34 GPs.

Aviation Troops

Aviation troops are obviously restricted in usage.

Ground Combat Units

There are 7 types of ground combat units: reconnaissance (recon), combat engineers, and Infantry; Light Armored Vehicles; artillery; tanks; and Amphibious Vehicles. The use of the land by ground combat units can be viewed from the perspective of duration and footprint (i.e., how much time a unit spends on the ground and to what level does a unit's activity impact the MCBCL ecosystem). Usually, the longer the

duration of time units spend on the ground will result in more intense and/or a greater impact on the ecosystem.

Reconnaissance, Combat Engineers, and Infantry

Recon, combat engineer, and Infantry units travel off-road on foot. Occasionally, these units will be accompanied by support/safety vehicles, but the movement of these vehicles is highly regulated (i.e., slow, deliberate movement, can't hit trees or remove vegetation).

Units can be broken into groups of various sizes. Recon engineers usually train as a small-fire team (i.e., group of 4+ troops) or as a squad (i.e., group of <13 troops); combat engineers usually train as a platoon (i.e., group of 41+ troops); and Infantry engineers usually train as a company (i.e., group of 167+ troops), but often will break up into platoons. Occasionally, these three types groups train as part of a complete battalion (i.e., 800 troops)

Fire teams, squads, and platoons can travel on foot over MCBCL training areas that are far from roads. Company- and battalion-sized units go off-road and train in the woods, but these groups tend to stay out of swamps and heavily vegetated areas without first breaking into smaller units. The deeper Marines get into the woods and the smaller the unit size, the less stationary the training activity conducted (i.e., Marines keep moving and do not set up semi-permanent camps). When combat engineers move into the woods, they behave like an Infantry unit, but when they have their heavy equipment with them, they behave more like artillery or tanks, limiting movement to roads, trails, and existing open areas.

Light Armored Vehicles (LAV)

An LAV is an all-terrain, all-weather, 8-wheeled vehicle with night capabilities that provides strategic mobility to reach and engage the threat; tactical mobility for effective use of fire power to defeat soft and armored targets; and battlefield survivability to conduct combat missions. The LAV is fully amphibious, with a maximum of 3 minutes preparation. LAV units travel in groups of a minimum of 4 vehicles. When not participating in amphibious operations (Figure 1), LAVs are restricted to tank trails, road, and open areas (similar to LZs).

Figure 1. LAV participating in an amphibious military task (i.e., crossing a stream).

Artillery and Tanks

Artillery and tanks tend to have long duration activities and big footprints, but are restricted to roads, tank trails, and existing open areas, and fire berms in established areas.

In theory, all vehicle (tracked and wheeled) traffic occurs in landing zones, on tank trails or roads, and on the beach. Occasionally, a High Mobility Multipurpose Wheeled Vehicle (HMMWV or Humvee) or LAV is driven in an open area; however, because off-road traffic in open areas is not authorized, this is an unusual occurrence.

Amphibious Units

An amphibious operation is a military operation launched from the sea and embarked upon using ships or craft by an amphibious force, with the primary purpose of introducing a landing force ashore to accomplish the assigned mission. Types of amphibious operations include assaults, withdrawals, demonstrations, and raids in a permissive, uncertain, or hostile environment. There are five types of AVs that train at MCBCL:

Landing Craft Air Cushion. LCACs transport the weapons systems, equipment, cargo, and personnel of the assault elements of the USMC Air/Ground Task Force, both from ship to shore and across the beach. An LCAC is a high-speed, fully amphibious landing craft that can cover an entire area of beach and is capable of carrying a payload of 60–75 tons (Figure 2).

Figure 2. Landing Craft, Air Cushion (LCAC) coming ashore.

Amphibious Assault Vehicle. The AAV is an armored assault, amphibious, tracked landing vehicle (Figure 3) that can carry troops in amphibious operations from ship to shore, through rough water and the surf zone. The engine compartment of the AAV can be completely water-sealed, making the vehicle seaworthy. Once on shore, an AAV can also carry troops to inland objectives. The AAV provides protected transport of up to 25 combat-loaded Marines through all types of terrain.

Figure 3. Amphibious assault vehicle (AAV) coming ashore.

Landing Craft Utility. The Landing Craft Utility (LCU) vehicle is designed to land/retrieve personnel and equipment (e.g., tanks, artillery, equipment, motor vehicles) after the initial assault waves of an amphibious operation. The LCU has the capability of sustained sea operations for approximately seven days (Figure 4).

Figure 4. Landing Craft Utility (LCU) vehicle transporting equipment.

Expeditionary Fighting Vehicle (EFV). The EFV is an amphibious vehicle that will replace the AAV and that provides the capability to maneuver combat at 20–25 knots in the water while loaded with a Marine rifle squad, as well as to maneuver cross country with agility and mobility equal or greater than that of the M1 Main Battle Tank. The EFV is a capable all-around weapon and, with water speeds of 23 to 29 miles per hour, can be launched from amphibious ships 25 miles or more offshore to reach the shore far more quickly than the current vehicle (Figure 5). The improved mobility of the EFV reduces the risk to U.S. Navy ships from missiles, aircraft, boats, and mines. On land, the EFV can achieve speeds of 45 miles an hour, with cross-country mobility equal to a M1 Abrams tank.

Figure 5. Expeditionary Fighting Vehicle (EFV) in swim mode.

Splash points are used by AVs to enter and exit water environments. Some splash points have been paved to reduce erosion (Figure 6), whereas others have been improved (Figure 7). Accessed from Onslow Beach and the New River, splash points are used by all AVs types (e.g., LCAC, AAV, EFV, LAV) except the LCU, which never leaves the beach for other destinations on Base.

Figure 6. Improved splash point.

Figure 7. Unimproved splash point.

The AAV, EFV, LAV, and LCAC all use the splash points that are along the beach and across the Intracoastal Waterway. The AAV, EFV, and LAV also use eight splash points between LZ Oriole and French Creek to travel across the New River to nine other splash points on the western side of the New River. These vehicles access the splash points by overland routes of tank trails. The LCAC is the only AV that also utilizes marsh areas. LCACs enter the New River inlet (from the ocean) and travel between two tidal creeks, covering a span of approximately 300m between these two entry points. LCACs exit the marsh at one point and then enter Mile Hammock Bay via the water, traveling a distance across the marsh of roughly 1000 meters. There are approximately 6 amphibious training events per year, and a training event can be up to 30 runs.

Natural Resources Management on MCBCL

The mission of MCBCL is to provide military training that promotes the combat readiness of operating forces. MCBCL, like all military installations, has needs or drivers that must be satisfied for the installation's readiness mission to continue without significant disruption. Additionally, legal or

regulatory drivers, such as the federal Endangered Species Act (ESA) and Clean Water Act (CWA), must be complied with to ensure continuance of the military mission. Unique to MCBCL are installation-specific drivers that are defined by the Base's mission, land uses to support the mission, and the geographic location and natural resources affected by the mission.

All natural resources management activities on MCBCL support the military mission. Marines depend on sustainable natural resources to provide the proper environment for training and operations. Training restrictions implemented for threatened and endangered species living on MCBCL demonstrate the effect that declining natural resources can have on the military mission.

MCBCL is committed to environmental protection, continual environmental improvement, and pollution prevention. MCBCL's environmental policy is to protect current and future training mission capabilities by respecting and maintaining the natural environment. This policy includes the following components:

- Conserving the air, land, and water resources as vital USMC assets
- Protecting the environment to ensure current and future military readiness through sustained realistic training opportunities
- Maintaining and enhancing the biodiversity of the ecosystem through integrated natural resources management
- Reviewing all proposed activities for potential environmental impacts in accordance with National Environmental Policy Act
- Minimizing the impact on the environment through environmental quality assessment, education, pollution prevention, and use of geographic information systems (GIS) technology
- Complying with all federal environmental requirements and promoting community outreach activities
- Fostering cooperation with surrounding communities by publicizing MCBCL's environmental initiatives and supporting joint environmental protection programs.

As technology improves and science expands, new information is provided for natural resources management. The professionals at MCBCL respond to this information to ensure a natural resources management program that embraces the latest scientific data and continues to provide a sustainable environment in which Marines may train.

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Appendix B

Prioritized List of MCBCL's Conservation and Water Quality Needs

Conservation and Water Quality Needs	Module /Source	Approach for addressing MCBCL's Needs
High Priority Needs		
Primary Nursery Area (PNA) mitigation/delineation	Coastal Wetland	1. Research the determination of French Creek as a freshwater PNA. 2. Evaluate applicability of trading restoration credits. 3. Evaluate mitigation efforts that could lead to PNA boundary alterations.
Onslow Beach erosion	Coastal Barrier	1. Quantify long- and short-term shoreline change. 2. Identify erosion "hot spots" and their causes. 3. Predict shoreline changes based on various weather conditions and management scenarios.
Air quality/smoke management	Atmospheric and Other SERDP-funded project	1. Implement an ambient air monitoring program. 2. Identify ecosystem sensitivities, stressors, and contributors to nitrogen and carbon. 3. Transition information from two other SERDP-funded projects *Characterization of Emissions and Air Quality Modeling for Predicting the Impacts of Prescribed Burns at DoD Lands* (Talat Odman) and *Advanced Chemical Measurements of Smoke from DoD-Prescribed Burns* (Tim Johnson).
Measuring good quality habitat for red cockaded woodpeckers (RCW)	Other SERDP-funded project	Transition information from *A Decision support system for Identifying and ranking critical habitat parcels on and in the vicinity of DoD Installations* (SI-1472; Jeff Walters)
N1/BT3 monitoring for whales/ marine mammals	Other SERDP-funded project	Transition information from *Predictive Spatial Analysis of Marine Mammal Habitat* (CS-1390; Andy Read/Pat Halpin/Larry Crowder/David Hyrenbach)
RCW flexibility for Range Development - Regional RCW credit	Other SERDP-funded project	1. Transition information from *Trading Habitat Patches for the RCW: Incorporating the Role of Landscape Structure and Uncertainty in Decision Making* (SI-1469; Michael Jones). 2. Transition information from *Habitat Connectivity for Multiple Rare, Threatened and Endangered Species On and Around Military Installations* (SI-1471; Aaron Moody)
Stormwater runoff reduction and water quality studies	Aquatic/ Estuarine	1. Employ sampling and analytical techniques to monitor water quality and develop methods for reducing runoff
Near field water quality studies	Aquatic/ Estuarine	1. Sampling and analysis of areas in proximity to wastewater effluent diffuser to characterize water quality.
Distinguish/quantify effects of point & non-point inputs nutrient, sediment and pathogen inputs.	Aquatic/ Estuarine	1. Bioassays of in situ nutrient and other pollutant effects on planktonic and benthic microalgae 2. Determine cause of algal blooms (nutrient and climate driven events).

Conservation and Water Quality Needs	Module /Source	Approach for addressing MCBCL's Needs
Water quality/ primary nursery areas	Aquatic/ Estuarine	1. Employ sampling/analytical techniques used for estuary
Physical-chemical-biological interactions & their control on WQ/habitat	Aquatic/ Estuarine	1. Deploy in stream, real-time physical/chemical profiling/sensing and sampling capabilities. Couple to nutrient-productivity dynamics and modeling
Medium Priority Needs		
Wetland (marsh) restoration opportunities in New River Estuary	Coastal Wetland	1. Evaluate past remediation efforts (shoreline stabilization). 2. Evaluate aerial extent of marshes based on historic aerial photographs. 3. Conduct water quality sampling and modeling to determine the wetland areas at greatest risk and where mitigation may be needed.
Species at Risk - beach amaranth	Coastal Barrier	1. Evaluate MCBCL's existing monitoring data. 2. Research ability to propagate and transplant species (no approach currently identified).
Species at Risk - sea turtles	Coastal Barrier	1. Evaluate MCBCL's existing sea turtle monitoring protocol and data. 2. Conduct research on hatchling predation.
Species at Risk - shorebirds	Coastal Barrier	1. Evaluate MCBCL's existing monitoring data. 2. Research use of overwash area on the south end of Onslow Beach.
Species at Risk - RCW	Terrestrial	1. Research stress hormone as indicator of RCW habitat quality and impacts of military training activity on RCW. 2. Determine habitat potential of pond pine (no approach currently identified).
Fire effects on vegetation, and quantifying/qualifying prescribed burns	Terrestrial	1. Determine ecosystems sensitivities to prescribe burn frequency and season. 2. Determine areas of good quality habitat.
Species at Risk - rough-leaved loosestrife	Terrestrial	1. Evaluate MCBCL's existing rough-leaved loosestrife monitoring protocol and data (no approach currently identified).
Habitat restoration and tactical vehicle off-road impacts	Terrestrial	1. Determine impacts of compaction from off-road vehicles on wiregrass (no approach currently identified). 2. Determine which training areas can best tolerate off-road vehicle use (no approach currently identified).
Northern Pocosin in Great Sandy Run Area (GSRA)	Terrestrial	No approach currently identified.
RCW monitoring	Other SERDP-funded project	Transition information from *Demographic and Population Response of Red-cockaded Woodpeckers on MCBCL to a Basewide Management Plan* (Jeff Walters)

Conservation and Water Quality Needs	Module /Source	Approach for addressing MCBCL's Needs
Additional military effects/RCW study	Other SERDP-funded project	Transition information from *Assessment of Training Noise Impact on the RCW* (CS-1083; Larry Pate)
Longleaf /loblolly decline	Other SERDP-funded project	Transition information from *Regenerating Longleaf Pine on Hydric Soils: Short- and Long-Term Effects on Native Ground-Layer Vegetation* (CS-1303; Joan Walker) and *Managing Declining Pine Stands for the Restoration of RCW Habitat* (SI-1474; Joan Walker)
Benthic organism Index of Biological Integrity (IBI)	Aquatic/ Estuarine	1. Use meiofaunal taxa composition to develop benthic indicators
Benthic-water column exchange and hypoxia research	Other SERDP-funded research	Transition data from *An Integrated Approach to Understand Relationships between Shallow Water Benthic Community Structure and Ecosystem Function* (CS-1335; Linda Schaffner/Iris Anderson)
Blue crab studies	Other	Transfer data from Martin Posey's (UNC-W) MCBCL funded study
Determine nutrient, sediment and pathogens loadings from the watershed; determine transformations of nutrients within the estuary. Determine interactive role of climatic/hydrologic roles	Aquatic/ Estuarine	1. Identify sources and loadings of nutrients, sediments and pathogens 2. Examine new vs. internally-regenerated nutrient sources and inputs 3. Determine inputs, effects and fates of nutrients, sediments and pathogens under hydrologically variable conditions 4. Model sediment-water column inputs and exchange of nutrients, sediments and pathogens
Identify and quantify nutrients controlling primary production, excess production and algal blooms	Aquatic/ Estuarine	1. Identify and quantify limiting nutrients 2. Identify and quantify sources of limiting nutrients 3. Establish thresholds of nutrient limitation and algal bloom 4. Target tributaries and estuarine segments not currently sampled. 5. Dynamic model to predict estuarine responses to nutrient inputs.
Determine causes and effects of harmful algal blooms (HABs). Link nutrient-productivity to hypoxia potentials	Aquatic/ Estuarine	1. Deploy microalgal indicators to examine HAB potentials and thresholds in water column and sediments 2. Develop indicators of productivity and community structure and assess stressor specific responses (algal blooms, hypoxia, food web perturbations)
Low Priority Needs		
Coliform counts - Freemans Creek (and other 303(d) TMDL identified tributaries)	Aquatic/ Estuarine	Pathogen tracking/source identification: 1. Differentiate between pathogen sources. 2. Partition nitrogen sources.

Conservation and Water Quality Needs	Module /Source	Approach for addressing MCBCL's Needs
Invasive species: alligator weed, *Phragmites*	Coastal Wetland	1. Determine aerial extent of *Phragmites*. 2. Determine affects of alligator weed on flood control (no approach currently identified).
Habitat restoration and tactical vehicle off-road impacts - maritime forest	Coastal Barrier	1. Survey biodiversity of maritime forests.

Appendix C

Sources of Monitoring Data Occurring Within or Near MCBCL

EMD Branch	Monitoring Activity	Status	Data[1]
Forestry	Timber/stand inventories (Ecosystem Management Model)	Ongoing	GIS layers
	Vegetation photo-points (to follow long-term veg changes)	Annual	Photographic
	Gypsy moth trapping	Annual	Spreadsheet/log book
	Southern pine beetle	As-needed basis	Spreadsheet/log-book
	Fuels research (seasonal dryness of fuels)	Ongoing	J. Reardon (Missoula Sciences Fire Lab, USFS)
	Air smoke monitoring data	Completed	D. Wade et. al
Threatened and Endangered Species	RCW - monitor 100 population	Annual	Jeff Walters/GIS layers
	RCW -inspect high traffic clusters to assess impacts	Weekly	Jay Carter (private consultant)
	Rough leaf loosestrife surveys	Annual	Spreadsheet/GIS layers
	Bald eagle surveys	Annual	Log book/database
	Mid-tide level GPS	1-2 measurements/ year	Under development
	Coastal golden rod survey	Annual	Spreadsheet/GIS layers
	Sea turtle surveys	Seasonal with nesting season	Log book/spread sheet/database
	Shorebirds surveys	Weekly presence-absence survey	Spreadsheet/database
	Turtle and shorebird predation/trapping program	Seasonal with turtle nesting season	Log book
	Sea beach amaranth surveys	Annual	Log book/GIS layer
Land and Wildlife	Wetlands (training areas monitored for impacts)	Ongoing	Log book/spreadsheet
	Training effects on soils and dunes	Annual, qualitative visual inspection	Log book/spreadsheet
	Soil erosion, in training areas, recently initiated	Categorical data from visual inspection	Log book/spreadsheet
	Non-native exotic flora and fauna monitoring	Annual, qualitative visual inspection	Log book/spreadsheet
	Deer monitoring, harvest/game management	Ongoing	Log book/spreadsheet
	Wood duck box monitoring	Annual	Log book/spreadsheet
	Quail surveys	Annual	Log book/spreadsheet
	Turkey surveys	Annual	Log book/spreadsheet
	Amphibians (frog calls) surveys	Seasonal	Log book/spreadsheet
	Alligator surveys	Annual	Log book/spreadsheet
	Shellfish sampling	Annual	Log book/GIS layer
	Fish pond population surveys	Annual	Log book/spreadsheet
	Cactus moth surveys	Annual	Log book/spreadsheet
	Creel surveys	Annual	Log book/spreadsheet
	Christmas bird counts	Annual	National database

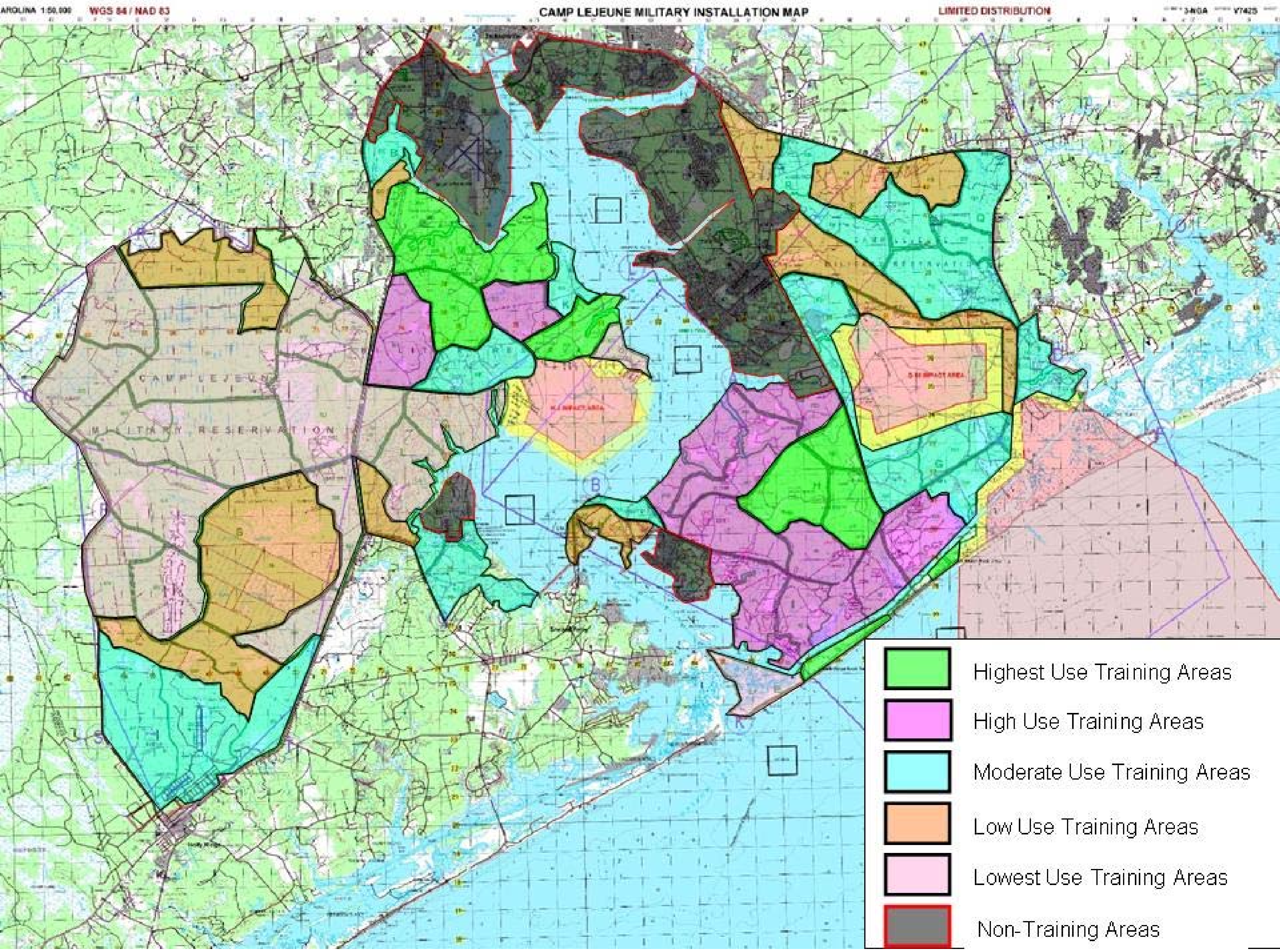
EMD Branch	Monitoring Activity	Status	Data[1]
	Shorebird & waterfowl counts (part of Atlantic Mig. Bird Initiative)	Annual	National database
	Migratory bird count (Int. Migratory Bird Day)	Annual	National database
	Rusty black birds, Smithsonian	Ongoing	Held by researchers
	Pocosin hydrology and vegetation monitoring (wetland mitigation site)	Ongoing	Spreadsheet/database
Water Quality	Storm-water monitoring	Annual	Spreadsheet
	Wastewater NPDES monitoring	Monthly	Spreadsheet
	Shellfish surveys	Annual	NC Division of Marine Fisheries
	Shellfish sanitation/bacteriological (shellfish sanitation program)	Annual	NCDENR
	Ambient water quality monitoring	Annual	NCDENR
	Water quality (water chemistry) monitoring	Annual	UNCW (Mike Mallin)
	Blue crab distribution of juveniles	Monthly	NSF-CRUI program at UNCW
Air Quality	Stationary emission points	Continuous	Spreadsheet/report
CLEO	Off-road recreational vehicle order compliance	Measured by # of violations	Log book/spreadsheet
Other: Range Control	Noise pollution (single-event noise monitoring)	Ongoing, in-house	Database

Notes:

[1] Unless otherwise noted, the monitoring activity is conducted by the Environmental Management Division, Installations and Environment Department, MCBCL.

Appendix D

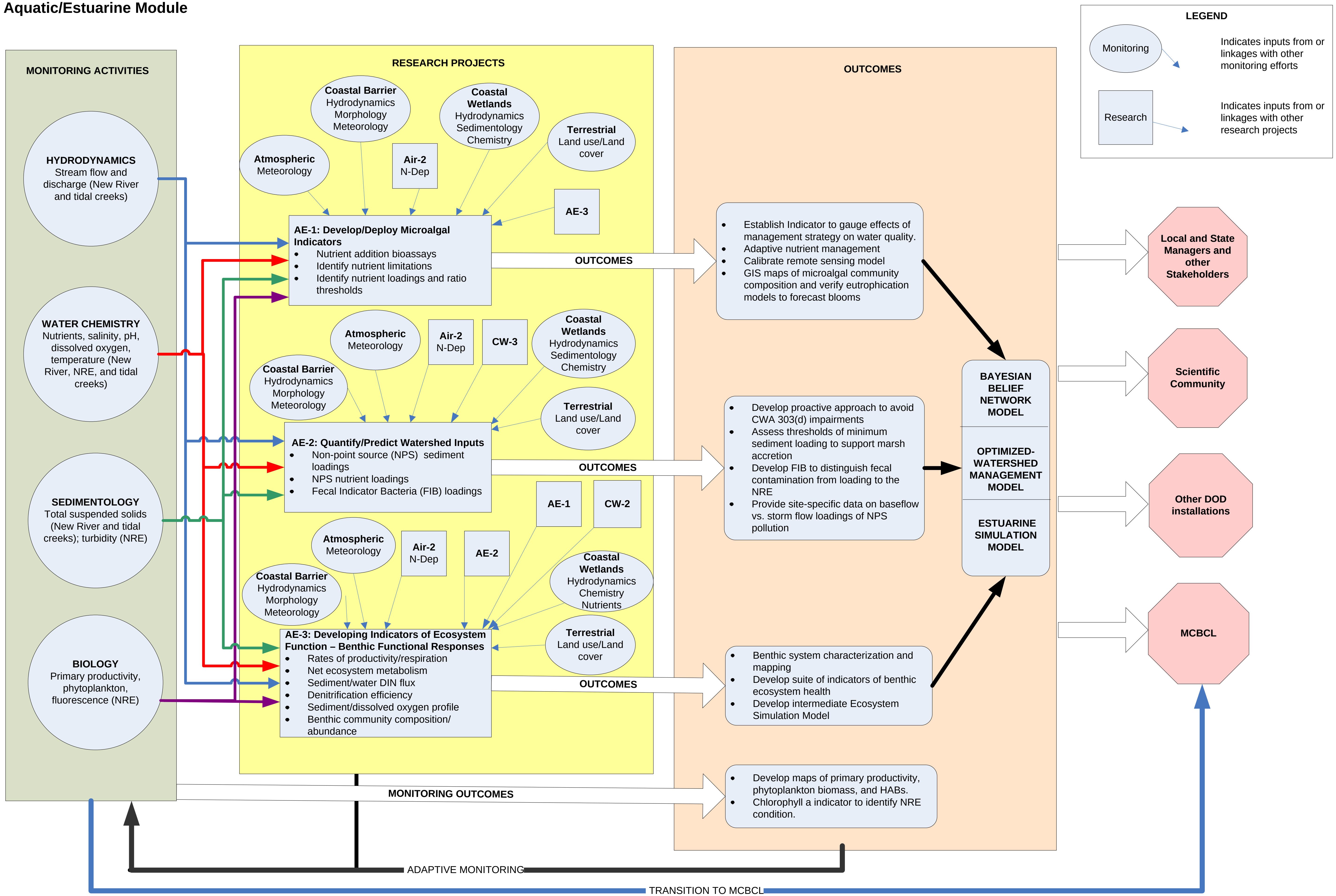
Preliminary Assessment of MCBCL Training Use Classification and Accessibility Map

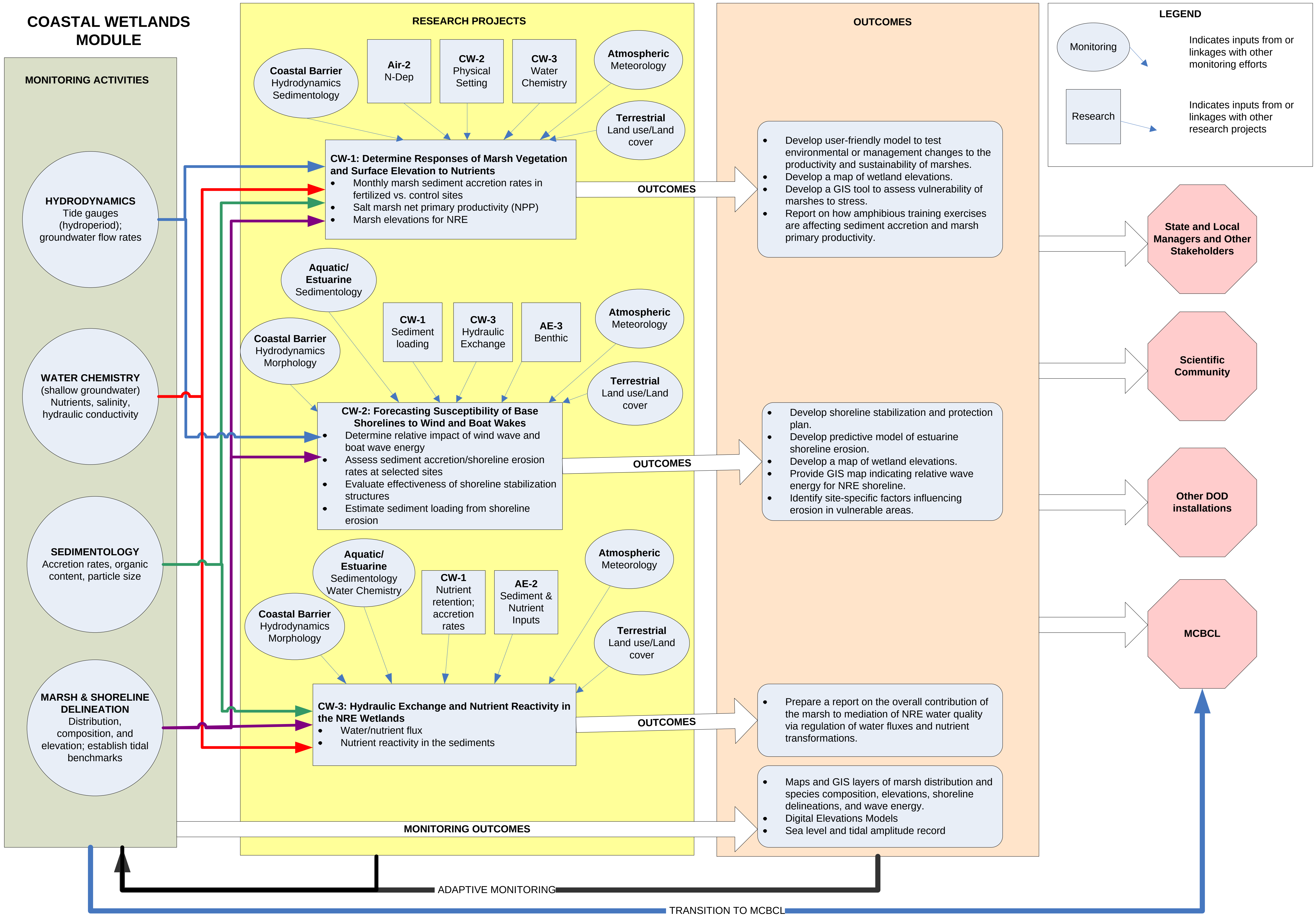

CAMP LEJEUNE MILITARY INSTALLATION MAP
WGS 84 / NAD 83
LIMITED DISTRIBUTION
CAMP LEJEUNE
MILITARY RESERVATION
Highest Use Training Areas
High Use Training Areas
Moderate Use Training Areas
Low Use Training Areas
Lowest Use Training Areas
Non-Training Areas

Appendix E

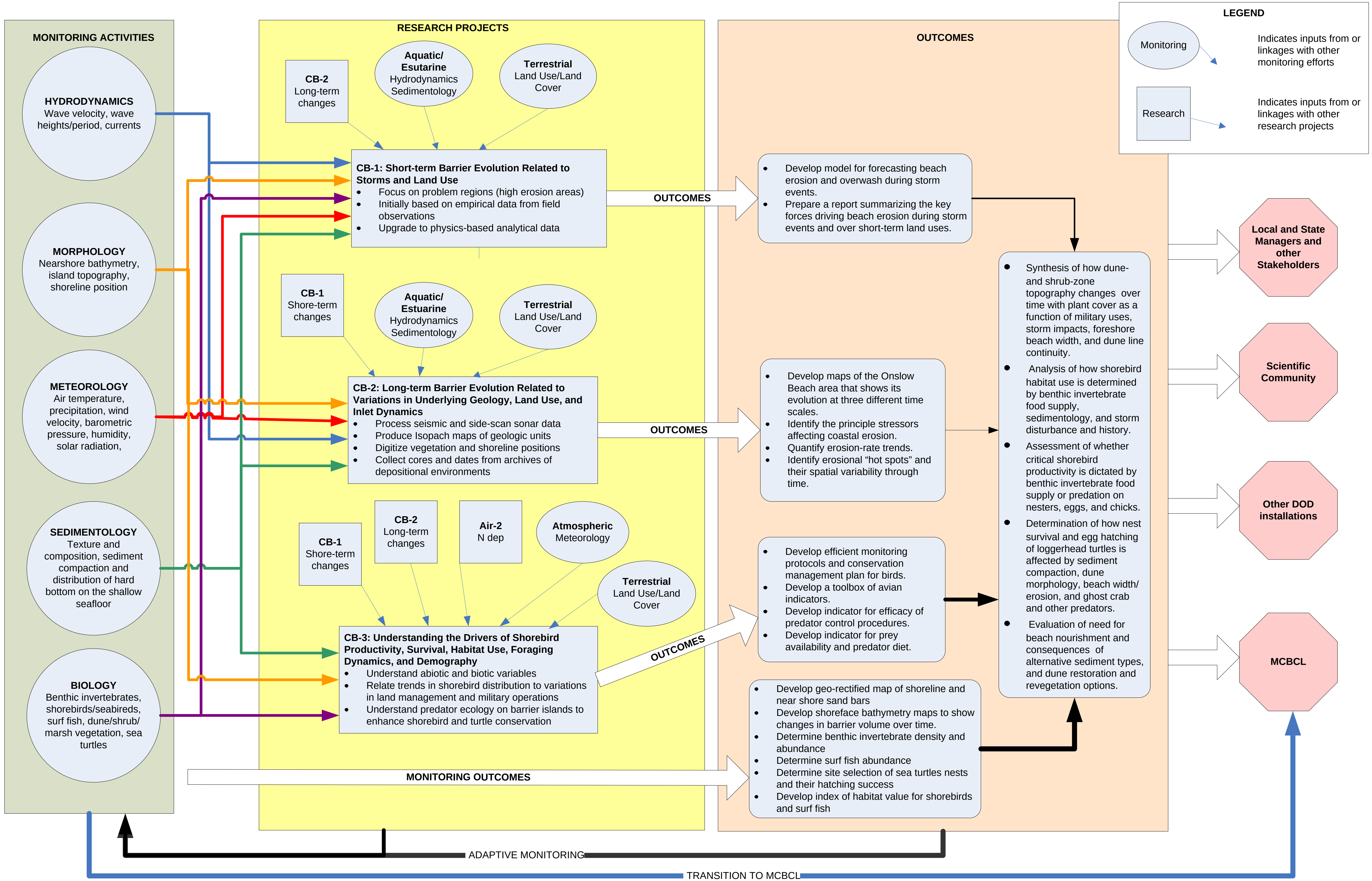
Ecosystem Module Roadmaps

Aquatic/Estuarine Module

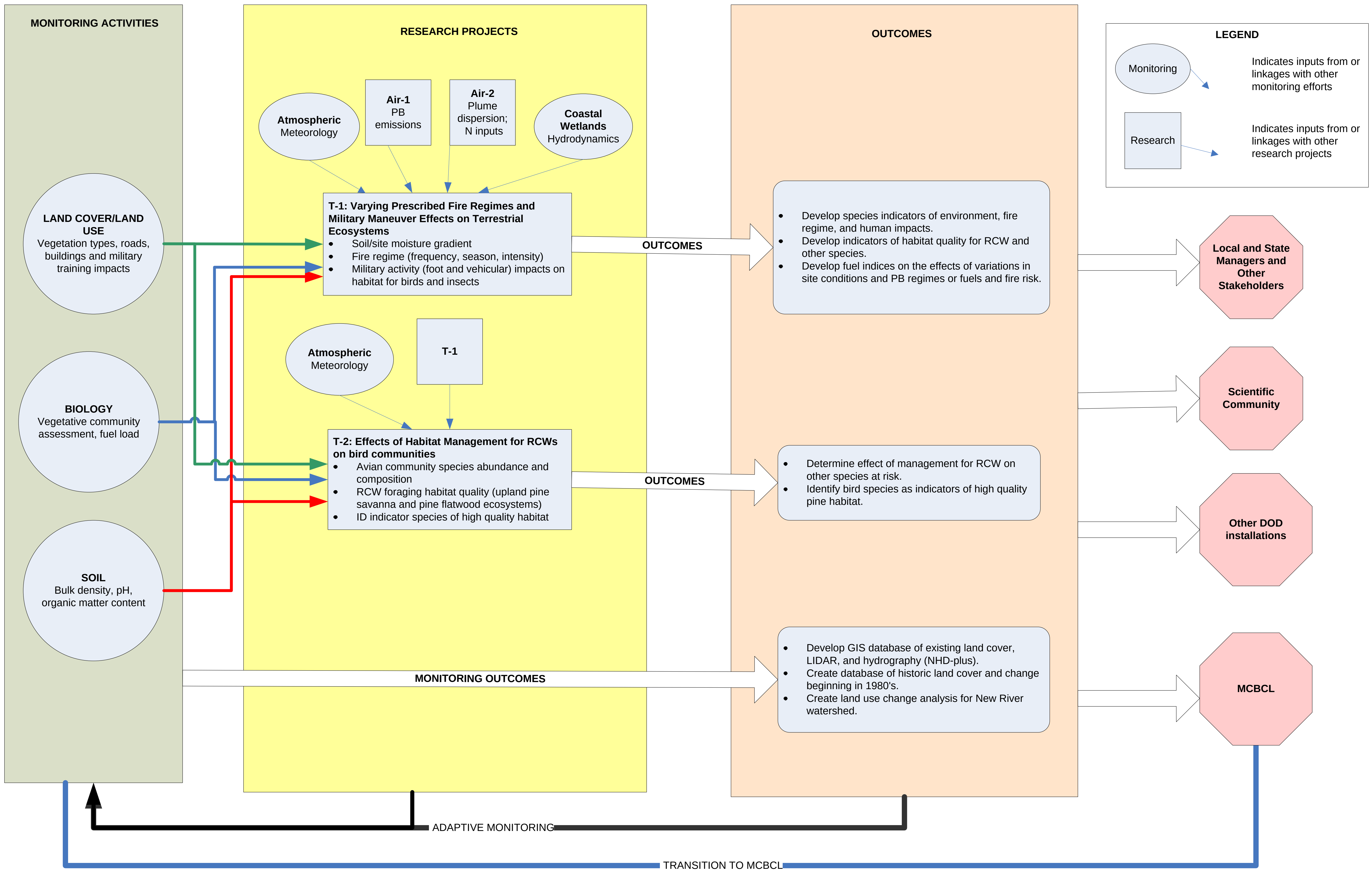


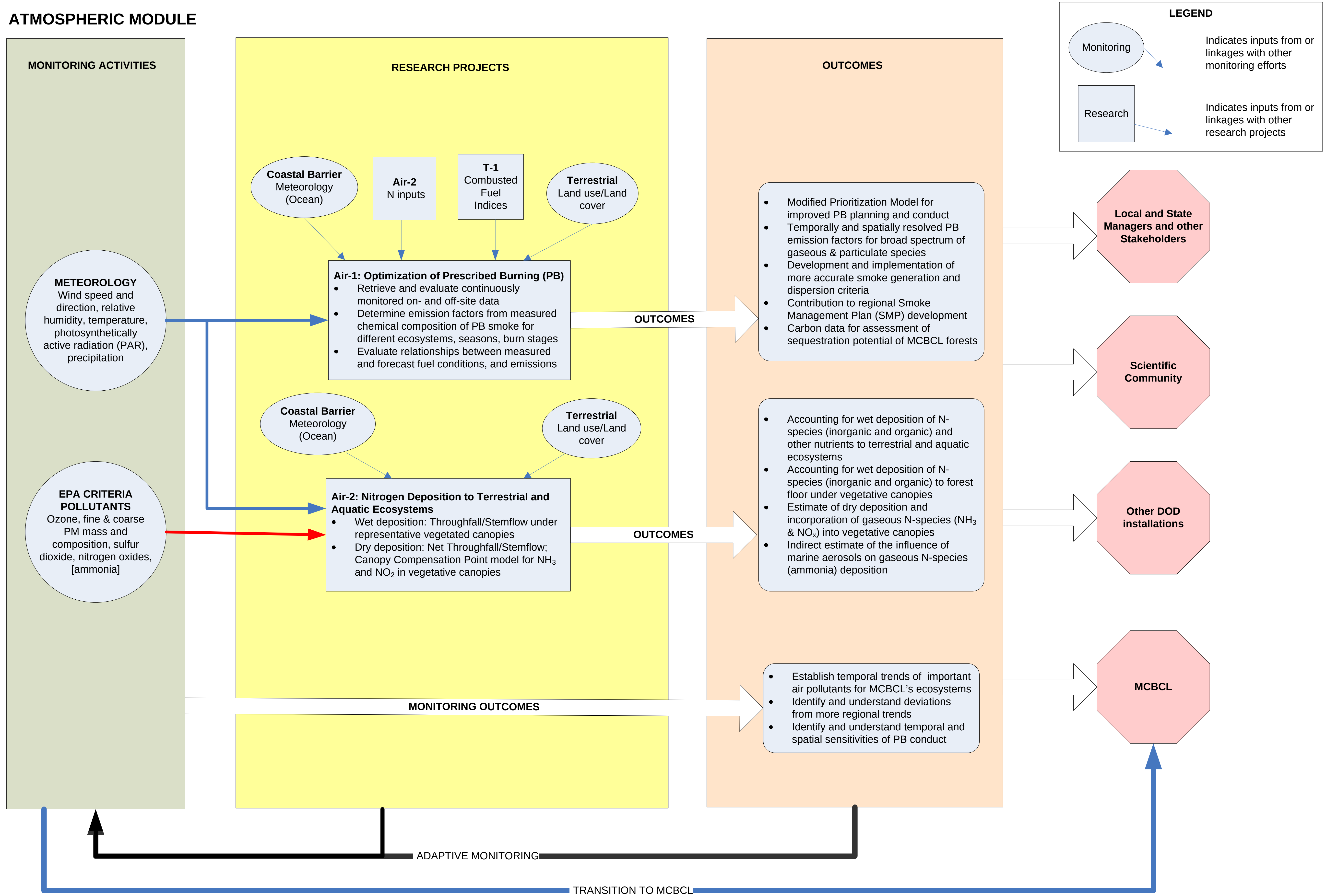

COASTAL WETLANDS MODULE
MONITORING ACTIVITIES
HYDRODYNAMICS Tide gauges (hydroperiod); groundwater flow rates
WATER CHEMISTRY (shallow groundwater) Nutrients, salinity, hydraulic conductivity
SEDIMENTOLOGY Accretion rates, organic content, particle size
MARSH & SHORELINE DELINEATION Distribution, composition, and elevation; establish tidal benchmarks
RESEARCH PROJECTS
Coastal Barrier Hydrodynamics Sedimentology
Air-2 N-Dep
CW-2 Physical Setting
CW-3 Water Chemistry
Atmospheric Meteorology
Terrestrial Land use/Land cover
CW-1: Determine Responses of Marsh Vegetation and Surface Elevation to Nutrients
• Monthly marsh sediment accretion rates in fertilized vs. control sites
• Salt marsh net primary productivity (NPP)
• Marsh elevations for NRE
OUTCOMES
Aquatic/ Estuarine Sedimentology
Coastal Barrier Hydrodynamics Morphology
CW-1 Sediment loading
CW-3 Hydraulic Exchange
AE-3 Benthic
Atmospheric Meteorology
Terrestrial Land use/Land cover
CW-2: Forecasting Susceptibility of Base Shorelines to Wind and Boat Wakes
• Determine relative impact of wind wave and boat wave energy
• Assess sediment accretion/shoreline erosion rates at selected sites
• Evaluate effectiveness of shoreline stabilization structures
• Estimate sediment loading from shoreline erosion
OUTCOMES
Aquatic/ Estuarine Sedimentology Water Chemistry
Coastal Barrier Hydrodynamics Morphology
CW-1 Nutrient retention; accretion rates
AE-2 Sediment & Nutrient Inputs
Atmospheric Meteorology
Terrestrial Land use/Land cover
CW-3: Hydraulic Exchange and Nutrient Reactivity in the NRE Wetlands
• Water/nutrient flux
• Nutrient reactivity in the sediments
OUTCOMES
MONITORING OUTCOMES
OUTCOMES
• Develop user-friendly model to test environmental or management changes to the productivity and sustainability of marshes.
• Develop a map of wetland elevations.
• Develop a GIS tool to assess vulnerability of marshes to stress.
• Report on how amphibious training exercises are affecting sediment accretion and marsh primary productivity.
• Develop shoreline stabilization and protection plan.
• Develop predictive model of estuarine shoreline erosion.
• Develop a map of wetland elevations.
• Provide GIS map indicating relative wave energy for NRE shoreline.
• Identify site-specific factors influencing erosion in vulnerable areas.
• Prepare a report on the overall contribution of the marsh to mediation of NRE water quality via regulation of water fluxes and nutrient transformations.
• Maps and GIS layers of marsh distribution and species composition, elevations, shoreline delineations, and wave energy.
• Digital Elevations Models
• Sea level and tidal amplitude record
LEGEND
Monitoring
Indicates inputs from or linkages with other monitoring efforts
Research
Indicates inputs from or linkages with other research projects
State and Local Managers and Other Stakeholders
Scientific Community
Other DOD installations
MCBCL
ADAPTIVE MONITORING
TRANSITION TO MCBCL

COASTAL BARRIER MODULE



TERRESTRIAL MODULE




ATMOSPHERIC MODULE
LEGEND
Monitoring
Indicates inputs from or linkages with other monitoring efforts
Research
Indicates inputs from or linkages with other research projects
MONITORING ACTIVITIES
RESEARCH PROJECTS
OUTCOMES
METEOROLOGY
Wind speed and direction, relative humidity, temperature, photosynthetically active radiation (PAR), precipitation
EPA CRITERIA POLLUTANTS
Ozone, fine & coarse PM mass and composition, sulfur dioxide, nitrogen oxides, [ammonia]
Coastal Barrier Meteorology (Ocean)
Air-2 N inputs
T-1 Combusted Fuel Indices
Terrestrial Land use/Land cover
Air-1: Optimization of Prescribed Burning (PB)
• Retrieve and evaluate continuously monitored on- and off-site data
• Determine emission factors from measured chemical composition of PB smoke for different ecosystems, seasons, burn stages
• Evaluate relationships between measured and forecast fuel conditions, and emissions
Coastal Barrier Meteorology (Ocean)
Terrestrial Land use/Land cover
Air-2: Nitrogen Deposition to Terrestrial and Aquatic Ecosystems
• Wet deposition: Throughfall/Stemflow under representative vegetated canopies
• Dry deposition: Net Throughfall/Stemflow; Canopy Compensation Point model for NH_3 and NO_2 in vegetative canopies
OUTCOMES
OUTCOMES
• Modified Prioritization Model for improved PB planning and conduct
• Temporally and spatially resolved PB emission factors for broad spectrum of gaseous & particulate species
• Development and implementation of more accurate smoke generation and dispersion criteria
• Contribution to regional Smoke Management Plan (SMP) development
• Carbon data for assessment of sequestration potential of MCBCL forests
• Accounting for wet deposition of N-species (inorganic and organic) and other nutrients to terrestrial and aquatic ecosystems
• Accounting for wet deposition of N-species (inorganic and organic) to forest floor under vegetative canopies
• Estimate of dry deposition and incorporation of gaseous N-species (NH_3 & NO_x) into vegetative canopies
• Indirect estimate of the influence of marine aerosols on gaseous N-species (ammonia) deposition
MONITORING OUTCOMES
• Establish temporal trends of important air pollutants for MCBCL's ecosystems
• Identify and understand deviations from more regional trends
• Identify and understand temporal and spatial sensitivities of PB conduct
Local and State Managers and other Stakeholders
Scientific Community
Other DOD installations
MCBCL
ADAPTIVE MONITORING
TRANSITION TO MCBCL

Defense Coastal/Estuarine Research Program (DCERP)

Baseline Monitoring Plan: Addendum I

July 3, 2008

For the period 2006 through 2011

Prepared for:

Strategic Environmental Research and Development Program (SERDP)

Prepared by:

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Acronyms and Abbreviations

ADCIRC	Advanced Circulation
ADCP	Acoustic Doppler Current Profiler
ANCOVA	analysis of covariance
AOC	area of concern
AVP	autonomous vertical profiler
BBN	Bayesian Belief Network
BL	boundary layer
BP	barometric pressure
C	carbon
CAA	Clean Air Act
CAFO	confined animal feeding operation
CDOM	colored dissolved organic matter
CFR	Code of Federal Regulations
CH_4	methane
Cl^-	chloride
CO	carbon monoxide
COOPS	Center for Operational Oceanographic Products and Services
CORMP	Coastal Ocean Research Monitoring Program
CVA	change vector analysis
CWA	Clean Water Act
DCERP	Defense Coastal/Estuarine Research Program
DEM	Digital Elevation Model
DIC	dissolved inorganic carbon
DIN	dissolved inorganic nitrogen
DIP	dissolved inorganic phosphorus
DO	dissolved oxygen
DOC	dissolved organic carbon
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DON	dissolved organic nitrogen
EA	Environmental Assessment
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
ESM	Estuarine Simulation Model
Fe^{+2}	ferrous
FIB	fecal indicator bacteria
FWS	U.S. Fish and Wildlife Service
GIS	geographic information systems
GPS	global positioning system
GSRA	Greater Sandy Run Area
H	hydrogen
H_2S	hydrogen sulfide
HAB	harmful algal bloom
HPLC	high performance liquid chromatography
ICW	Intracoastal Waterway
INRMP	*Integrated Natural Resources Management Plan*

LCAC	Landing Craft Air Cushion
LIDAR	Light Detection and Ranging
MARSOC	Marine Special Operations Command
MCASNR	Marine Corps Air Station New River
MCBCL	Marine Corps Base Camp Lejeune
MEM2	Marsh Elevation Model
MERIS	medium-spectral resolution, imaging spectrometer
µg/L	micrograms/liter
mg/L	milligrams/liter
MHW	mean high water
MODIS	moderate resolution imaging spectroradiometer
MOU	Memorandum of Understanding
MORPHOUS	modeling relevant physics of sedimentation
N	nitrogen
NAAQS	national ambient air quality standards
NCDAQ	North Carolina Division of Air Quality
NCDENR	North Carolina Department of Environment and Natural Resources
NCDWQ	North Carolina Division of Water Quality
NFDRS	National Fire Danger Rating System
NAVFAC ESC	Naval Facilities Engineering Service Center
NH_3	ammonia
NH_4+	ammonium
NO_2	nitrogen dioxide
NO_3	nitrate
NOAA	National Oceanic and Atmospheric Administration
NO_x	nitrogen oxide
NPDES	National Pollutant Discharge Elimination System
NRE	New River Estuary
NWIS	National Weather Information System
NWS	National Weather Service
O_3	ozone
OPUS	Online Positioning System
OSC	On-site Coordinator
P	phosphorus, precipitation
PAR	photosynthetically active radiation
Pb	lead
PB	prescribed burning
PI	Principal Investigator
PM	Program Manager, particulate matter
PM_c	coarse particulate matter
$PM_{2.5}$, PM_{fine}	(fine) particulate matter with aerodynamic diameter smaller 2.5 microns
PM_{10}	particulate matter with aerodynamic diameter smaller 10 microns
$PM_{10\text{-}2.5}$, PM_c	(coarse) particulate matter aerodynamic diameter with between 2.5 and 10 microns)
PO_4^{-3}	phosphate
PP	primary productivity
PPT	precipitation
QA	quality assurance
QC	quality control
RCC	Regional Coordinating Committee
RCW	red-cockaded woodpecker

RDBS	Relational Database Management System
RH	relative humidity
RTI	RTI International
RTK	real-time kinetic
SAV	submerged aquatic vegetation
SE	standard error
SERDP	Strategic Environmental Research and Development Program
SET	surface elevation table
SI	Sustainable Infrastructure
SO_2	sulfur dioxide
SO_4^{-2}	sulfate
SOA	secondary organic aerosol
SOP	standard operating procedure
SRP	soluble relative phosphate
SWAN	Simulating Waves Nearshore Model
TAC	Technical Advisory Committee
TBD	to be determined
TM	Thematic mapper
TMDL	total maximum daily load
TSS	total suspended solid
UNC-IMS	University of North Carolina Institute of Marine Sciences
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
USMC	U.S. Marine Corps
VOC	volatile organic compounds
WCI	water clarity index
WD	wind direction
WQI	water quality index
WS	wind speed
WSM	Watershed Simulation Model
WWTP	wastewater treatment plant
YSI	Yellow Springs Instruments, Inc.

Note: The purpose of the Defense Coastal/Estuarine Research Program (DCERP) Baseline Monitoring Plan is to describe the proposed DCERP baseline monitoring program that is being conducted at Marine Corps Base Camp Lejeune (MCBCL) to provide a historic reference of selected environmental parameters over the duration of the program. At the end of DCERP, it is the ultimate goal to transition to MCBCL a scaled-down version of the baseline monitoring program that identifies key measurement parameters for continued monitoring.

The baseline monitoring program is viewed as an adaptive program in which monitoring may be adjusted over time in response to weather events, the availability of more efficient methods, and new information gained from ongoing monitoring and research efforts. The purpose of this document is to indicate changes to the DCERP monitoring program that have occurred since the implementation of the DCERP Baseline Monitoring Plan in July 2007. This document retains the same numbering of sections, tables, and figures as the original DCERP Monitoring Plan and should be used in conjunction with this document.

Executive Summary

No changes to this section.

1.0 Introduction

No changes to this section.

2.0 Program Organization

The Defense Coastal/Estuarine Research Program (DCERP) is a collaborative effort between the Strategic Environmental Research and Development Program (SERDP), the Naval Facilities Engineering Service Center (NAVFAC ESC), Marine Corps Base Camp Lejeune (MCBCL), and the RTI DCERP Team. **Figure 2-1** illustrates the overall organization and lines of communication of the program. Please note the abbreviation for the Naval Facilities Engineering Service Center is now NAVFAC ESC.

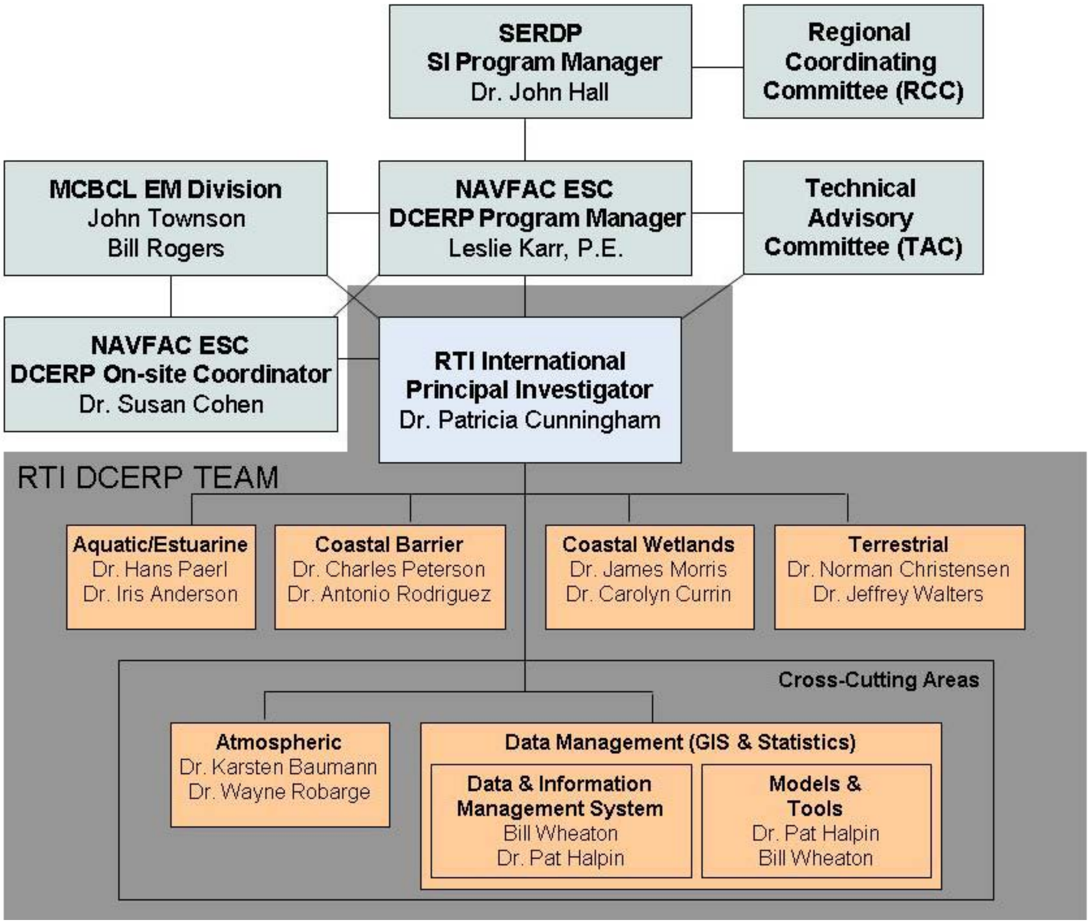


Figure 2-1. Organization of DCERP.

3.0 DCERP Overarching Strategy

No changes to this section.

4.0 Purpose of the Baseline Monitoring Plan

4.1 Summary of Monitoring Activities

The DCERP baseline monitoring program is described in the DCERP Baseline Monitoring Plan and includes the activities presented in **Table 4-1**.

Table 4-1. Summary of Module-Specific DCERP Baseline Monitoring Program Activities

Modules	Activities
Aquatic/ Estuarine[a]	Hydrodynamics: Stream flow and discharge (New River and tributary creeks) Chemistry: Nutrients, salinity, pH, oxygen, temperature (New River, New River Estuary [NRE], and tributary creeks) Sedimentology: Total suspended solids (New River and tributary creeks), turbidity (NRE) Biology: Primary productivity, phytoplankton, fluorescence (NRE)

Modules	Activities
Coastal Wetlands	Land cover and shoreline erosion: Location, elevation Hydrodynamics: Tide gauges (hydroperiod) Chemistry: Nutrients, salinity, hydraulic conductivity (shallow groundwater) Sedimentology: Accretion rates, organic content, particle size
Coastal Barrier	Hydrodynamics: Wave velocity, wave heights/period, currents, shoreline position, morphology Meteorology (ocean): Air temperature, wind velocity, barometric pressure, humidity, solar radiation Sedimentology: Texture, compaction, composition, sediment volume Biology: Benthic invertebrates, fish, shorebirds/seabirds, dune/shrub/marsh vegetation, sea turtles
Terrestrial	Land cover/land use: Determine changes in land cover/land use (vegetation types, buildings, roads) Biology: Vegetative community assessment, fuel load Soil: Soil bulk density, pH, organic matter content
Atmospheric	Meteorology (air): Wind speed, wind direction, relative humidity, temperature, photosynthetically active radiation, precipitation U.S. Environmental Protection Agency criteria pollutants: Ozone and fine and coarse particulate matter (mass)

[a] Sedimentology, chemistry, and biology of the NRE benthic zone are characterized in Research Project AE-3.

DCERP has been designed to study linkages among the various ecosystem components. **Table 4-2** has been revised to identify which module team will be responsible for collecting selected data and also shows the integrated nature of this Baseline Monitoring Plan by identifying other modules that use this same data.

Table 4-2. Monitoring Data Being Collected and Used by Various Modules[a]

Aquatic/Estuarine	Coastal Wetlands	Coastal Barrier	Terrestrial	Atmospheric
New River: flow, discharge, nutrients, sediment	New River: flow and sediment			
Tributary creeks: flow, temperature, nutrients, sediment	Tributary creeks: flow, nutrients, sediment			
New River Estuary: photosynthetically active radiation (PAR), primary productivity, nutrients, sediment, chlorophyll *a*, phytoplankton	New River Estuary: nutrients, sediment, primary productivity			
Land cover and shoreline erosion	Land cover and shoreline erosion	Land cover and shoreline erosion	Land cover and shoreline erosion	
Marsh surface elevation: tide gauge	Marsh surface elevation: tide gauge	Marsh surface elevation: tide gauge	Marsh surface elevation: tide gauge	
Nutrient flux in marsh groundwater	Nutrient flux in marsh groundwater			

Aquatic/Estuarine	Coastal Wetlands	Coastal Barrier	Terrestrial	Atmospheric
Hydrodynamics: wave velocity, direction and period, currents	Hydrodynamics: wave velocity, direction and period, currents	Hydrodynamics: wave velocity, direction and period, currents		
Offshore weather data	Offshore weather data	Offshore weather data	Offshore weather data	Offshore weather data
Geomorphology: shoreface bathymetry and barrier morphology	Geomorphology: shoreface bathymetry and barrier morphology	Geomorphology: shoreface bathymetry and barrier morphology		
		Sedimentology: texture, compaction, composition		
		Biology: benthic invertebrates, surf fish and shorebird, plant cover		
Land use/cover data	Land use/cover data	Land use/cover data	Land use/cover data	Land use/cover data
			Flora: species composition and diversity	Flora: species composition and diversity
			Forest floor and soils: fuel load, bulk density	Forest floor and soils: fuel load, bulk density
Land-based weather data: wind speed/ direction, barometric pressure (BP), relative humidity (RH), PAR	Land-based weather data: wind speed/ direction, BP, RH, PAR	Land-based weather data: wind speed/ direction, BP, RH, PAR	Land-based weather data: wind speed/ direction, BP, RH, PAR, ozone, particulate matter	Land-based weather data: precipitation, wind speed/direction, BP, RH, PAR, ozone, particulate matter

[a] In each row, the blue box identifies the module collecting the data; white boxes indicate modules that will use the data.

5.0 Setting of MCBCL

No changes to this section.

6.0 Module-Specific Baseline Monitoring

6.1 Aquatic/Estuarine Module

6.1.1 Introduction

No changes to this sub-section.

6.1.2 Monitoring Objectives and Activities

The Aquatic/Estuarine Module monitoring program is summarized in **Table 6-1. Additional sites have been added to the creeks and estuarine monitoring components.**

Table 6-1. Aquatic/Estuarine Module Monitoring Components

Area	Variable	Spatial Scale	Temporal Scale
New River	Stream flow and discharge	New River at Jacksonville	Continuous
	Nutrients and sediment	New River at Jacksonville	Monthly (outgoing tide)
	Water temperature, dissolved oxygen (DO), pH, salinity	New River at Jacksonville	Monthly in addition to nutrient/sediment sampling
Tributary creeks	Water level (stream flow) and temperatures	10 stations (paired)	Continuous
	Nutrients (dissolved inorganic nitrogen [DIN], dissolved inorganic phosphorus [DIP], dissolved organic nitrogen [DON], total nitrogen [N], and total phosphorus [P]), total suspended solids (TSS), fecal indicator bacteria (FIB)	10 stations (paired)	Monthly (base flow); episodic (storm flow)
New River Estuary—water column	Fluorescence (chlorophyll *a*), colored dissolved organic matter (CDOM), DIN, N, DIP, P, TSS	8 stations (8 vertical profiling and 2 continuous autonomous vertical profilers [AVPs])—longitudinal from New River to Inlet	Monthly for profiles and data flow, year-round for AVPs; more intensive (March–October)
	Photosynthetically active radiation (PAR), salinity, water temperature, DO, pH, turbidity, flow, precipitation	8 stations (8 vertical profiling and 2 continuous AVPs)—longitudinal from New River to Inlet.	Monthly for profiles and data flow, year-round for AVPs more intensive (March–October)
	Primary productivity (PP), chlorophyll *a* by fluorometry and high performance liquid chromatography (HPLC), phytoplankton pigments/counts	8 stations (8 vertical profiling and 2 continuous AVPs)—longitudinal from New River to Inlet	Monthly for profiles AVPs and data flow

Note: The benthic zone of the NRE will be characterized by Research Project AE-3. See the DCERP Research Plan.

6.1.3 Benefit to MCBCL

No changes to this sub-section.

6.1.4 Aquatic/Estuarine Module Monitoring Components

6.1.4.1 New River

No changes to this monitoring activity.

6.1.4.2 Tributary Creeks (Name Changed from Tidal Creeks)

Because of access issues, site issues affecting instrumentation, and our continuous consideration of which sites will best capture both the estuarine gradient and the military impact gradient, our site selection has slightly changed. The proposed stations in Wilson Bay, Town Creek, and Chadwick Bay have been replaced by Airport Creek, Codgel Creek, and Courthouse Bay, respectively. The station at Town Creek was an attempt to monitor the runoff from the K-2 impact area; unfortunately, access was restricted in this area. During field investigations to locate appropriate sampling stations, equipment was temporarily setup

in small creeks near Camp Johnson and Tarawa Terrace. Preliminary results have prompted us to permanently add these two stations into the DCERP monitoring program.

6.1.4.2.1 Objective(s)

No changes to this sub-section.

6.1.4.2.2 Relevance to the Base

No changes to this sub-section.

6.1.4.2.3 Scale

No changes to this sub-section.

6.1.4.2.4 Linkages Within Module and Among Other Modules' Monitoring Components

No changes to this sub-section.

6.1.4.2.5 Methods

Spatial/Site Locations

The tidal creek monitoring sites are distributed throughout the estuarine salinity gradient and are representative of MCBCL land uses (e.g., industrial, forested, urban [non-industrial]). All creek monitoring stations will be sited above the range of tidal influence. The sites are illustrated in **Figure 6-3** and are identified as follows:

1. Oligohaline—Site 3: Airport Creek (Impacted—Marine Corps Air Station New River [MCASNR]); Site 4: Southwest Creek (Not impacted—forest)
2. Mesohaline—Site 7: Codgel Creek (Impacted—industrial); Site 8: French Creek (Not impacted—forest)
3. Polyhaline—Site 5: Courthouse Bay (Impacted—urban); Site 6: Traps Creek (Not impacted—forest)
4. Backbarrier—Site 9: Freeman Creek (Impacted—bombing range), Site 10: Gillets Creek (Not impacted—forest)
5. Oligohaline—Site 11: Tarawa Terrace (Impacted—residential), Site 12: Camp Johnson (Not impacted—forest)

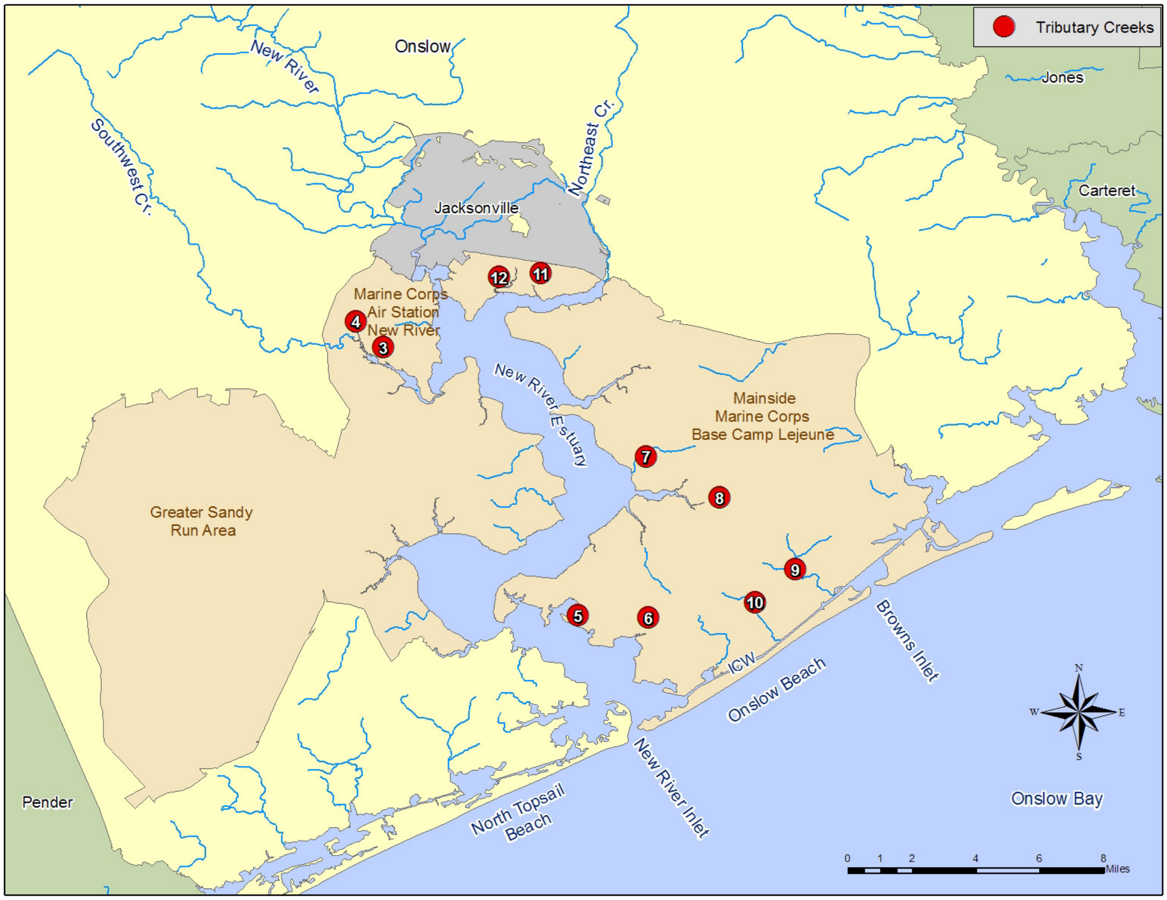


Figure 6-3. Tributary creek monitoring stations.

6.1.4.2.6 Data Analysis, Products, and Outcomes

No changes to this sub-section.

6.1.4.3 New River Estuary—Water Column Chemistry

We are employing two additional profiling stations that will be co-located with the automatic vertical profiling (AVP) sites. This increases the number of profiling stations from 6 to 8 that are sampled once a month. These additional stations provide greater spatial resolution in the mid-estuarine region, where historically, algal blooms and hypoxic events have occurred. These stations will also enable us to compare and cross-calibrate data for process-related, statistical, and, ultimately, modeling purposes. Collecting physical–chemical data at the two additional profiling stations will complement the data collected by the AVPs and will be used to calibrate the AVPs. This is a greater level of activity than originally proposed in the DCERP Baseline Monitoring Plan, but we believe that it is important to have the comparative profiling/AVP data. So far, we have been able to work on this additional task by using existing personnel and completing it within the time allotted.

Figure 6-4 illustrates the location of the sampling stations for this monitoring component. The locations have shifted slightly from the map in the Baseline Monitoring Plan, but in general are in the same location. The sites are distributed throughout the estuarine salinity gradient and are also in pairs of high and low impact from military operations, respectively.

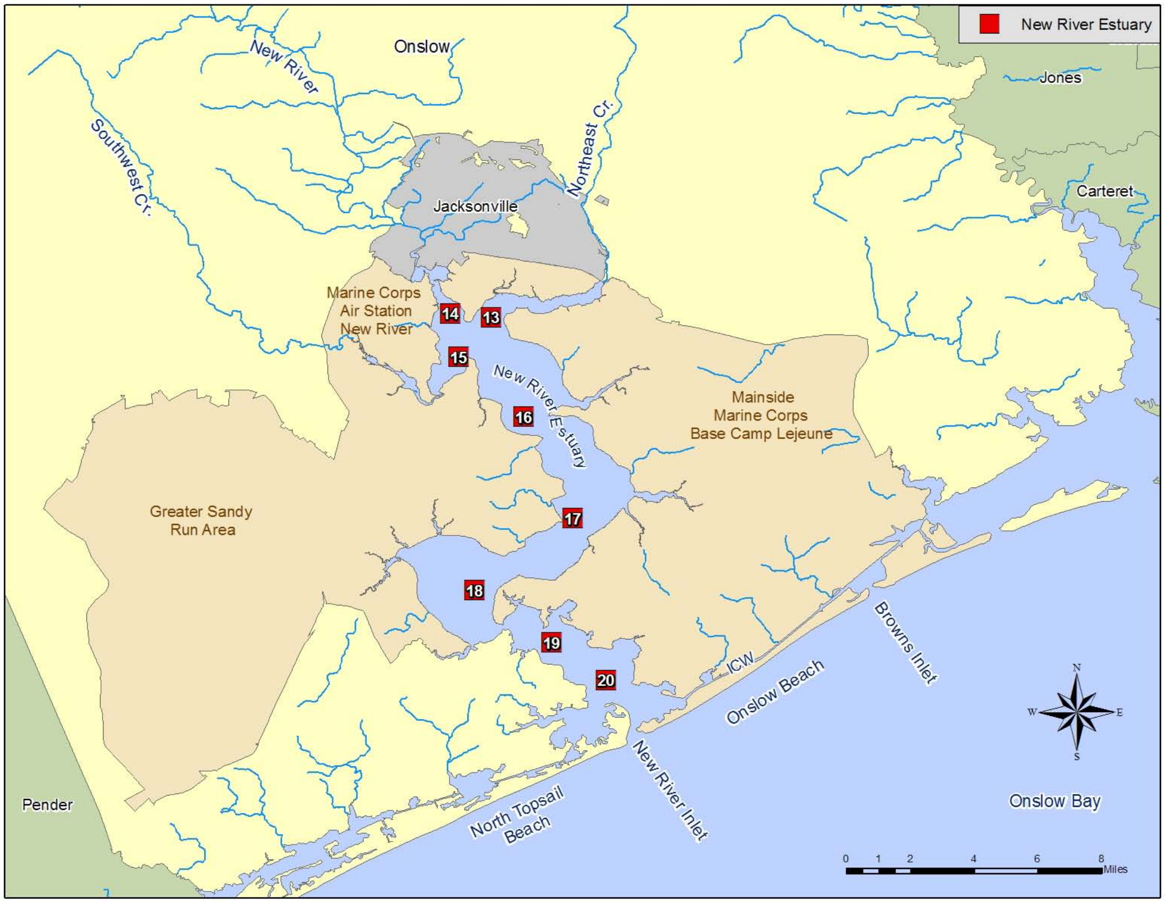


Figure 6-4. New River Estuary—water column chemistry monitoring stations.

6.1.4.4 New River Estuary—Water Column Primary Producers

Two additional profiling stations are being employed and these will be co-located with the AVP sites. These additional stations provide greater spatial resolution in the mid-estuarine region, where historically, algal blooms and hypoxic events have taken place. In addition, these stations will enable us to compare and cross-calibrate data for process-related, statistical, and, ultimately, modeling purposes. Collecting physical–chemical data at the two additional profiling stations will complement the data collected by the AVPs and will be used to calibrate the AVPs. This is a greater level of activity than originally proposed in the DCERP Baseline Monitoring Plan, but we believe that it is important to have the comparative profiling/AVP data. So far, we have been able to work on this additional task by using existing personnel and completing it within the time allotted. Water column primary productivity is being measured at same sampling stations shown in Figure 6-4 (omitted **Figure 6-5**).

6.2 Coastal Wetlands Module

6.2.1 Introduction

No changes to this sub-section.

6.2.2 Coastal Wetlands Module Objectives and Activities

Table 6.5 has been revised to reflect changes in spatial and temporal scales, which are described in more detail in the following sub-sections.

Table 6-5. Coastal Wetlands Module Monitoring Components

Component	Variables	Spatial Scale	Temporal Scale
Land cover and shoreline erosion	Wetland habitat distribution and composition	Entire New River Estuary (NRE)	Photos and imagery from 1938 to present
	Marsh composition and abundance by species, density, mean stem height	9 stations (Sites 1–9)	Annually
	Shoreline location and elevation	Entire NRE; 8 stations in detail (Sites 4–11)	Biennially and event based (dependent on the availability of imagery)
Marsh surface elevation	Marsh surface elevation (sediment accretion)	9 stations (Sites 1–9)	Spring and fall
	Water level, temperature, salinity (for hydroperiod calculations)	2 stations (Sites 13–14)	Continuous 6-minute intervals
	Sediment (percentage of organic content, particle size)	11 stations (Sites 1–11)	Biennially
	Digital Elevation Models—surface elevation	11 stations (Sites 1–11)	Biennially and event based
Nutrient chemistry	Ammonia (NH_3^+), nitrate (NO_3^-), salinity, sulfate (SO_4^{-2}), dissolved organic nitrogen (DON), soluble reactive phosphorus (SRP), ferrous, hydrogen sulfide, dissolved organic carbon (DOC), hydraulic gradient, hydraulic conductivity	3 stations (Sites 1, 4, 12)	Chemistry—seasonal; Hydrology—continuous

6.2.3 Benefit to MCBCL

No changes to this sub-section.

6.2.4 Coastal Wetlands Module Monitoring Components

6.2.4.1 Landcover and Shoreline Erosion

6.2.4.1.1 Objectives

No changes to this sub-section.

6.2.4.1.2 Relevance to the Base

No changes to this sub-section.

6.2.4.1.3 Scale

No changes to this sub-section.

6.2.4.1.4 Linkages within the Module and among other Modules' Monitoring Components

All monitoring activities within the Coastal Wetlands Module are still closely coordinated with the Coastal Wetlands Module research projects and the Aquatic/Estuarine Module research and monitoring sites. We are co-located with Research Project AE-3 at Sites 1, 4, 5, 6, 7, 8, and 9 as shown in **Figure 6-7**. This co-location of sites with the Aquatic/Estuarine Module will allow us to examine the relationship between marsh processes and the structure and function of adjacent subtidal communities. We will coordinate sampling of the marsh behind the barrier island at Site 2 with the Coastal Barrier Module monitoring activities. Changes in marsh vegetation and shoreline erosion may have significant effects on

variables measured by the Aquatic/Estuarine and Coastal Barrier modules, and by sharing sites we will be able to assess these linkages.

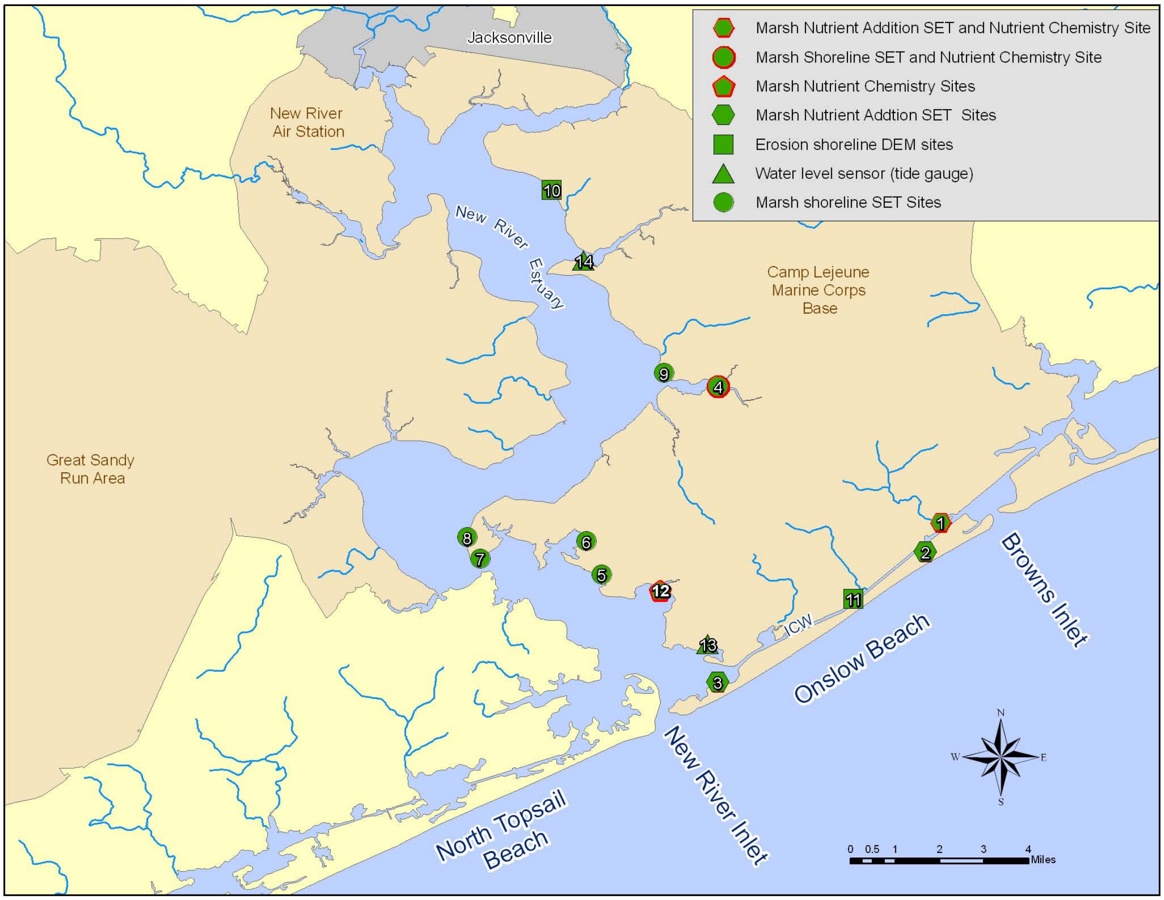


Figure 6-7. Map of monitoring stations for the Coastal Wetlands Module.

6.2.4.1.5 Methods

Spatial/Site Locations

We have modified the distribution of stations to accommodate alterations in Research Projects CW-1 and CW-2, and this will influence the areas selected for detailed analysis and ground-truthing in support of this monitoring activity. The sites are no longer classified as "Marsh Sites" and "Shoreline Sites." Refer to the spatial scale in Table 6-5 for a list of the stations where the monitoring activities occur. Figure 6-7 shows the location of all the monitoring stations, as well as the research stations because many of these activities are co-located.

- Site 1 (Freeman Creek): Moderate military use (G-10 impact zone runoff), higher salinity, proximity to barrier island.
- Site 2 (Onslow Beach Backbarrier): Not-impacted by military use, high salinity, proximity to barrier island
- Site 3: (Mile Hammock Bay): High military use (landing craft air cushion [LCAC]); This site has the closest proximity to the New River Inlet
- Sites 4 and 9 (French Creek, inside and outside splash point): Moderate impact (runoff from G-10 impact area; splash points at mouth), lower salinity

- Sites 5 and 6 (Courthouse Bay, outside and inside splash point): Moderate impact from cantonment area and splash point, higher salinity
- Sites 7 and 8 (Highway 172 bridge, inside and outside): Moderate impact from boat traffic, moderate salinity.
- Site 10 (Hospital Point): Area with a stabilized shoreline, low salinity, wave exposure setting
- Site 11 (Intracoastal Waterway [ICW]): Area with a stabilized shoreline, high salinity, wave exposure setting
- Site 12 (Traps Creek): forested training lands, moderate salinity
- Sites 13 and 14 (Mile Hammock Bay and Gottschaulk Marina): Tide gauges

Land cover will occur for the entire NRE; however, available aerial imagery is still being evaluated. Marsh species composition and density will occur at Sites 1–9. The total number of stations was reduced for the original Monitoring Plan; however, we have increased the replication within each station. Shoreline location and elevation will occurs at Sites 4–11; with paired stations at French Creek, Courthouse Bay, and the Highway 172 bridge.

No changes to the temporal scale, personnel, or variables of this monitoring activity.

Field and Laboratory Procedures

Sampling Design and Collection.

Overall, there were no changes to the sample design and collection procedures; however, available aerial photography and imagery are still being obtained and examined. Therefore, additional modifications to this plan may be necessary after all available imagery is reviewed.

6.2.4.2 Marsh Surface Elevation

Due to logistical and financial constraints, we reduced the overall number of sites and increased the replication within sites in support of Research Project CW-1. We installed a total of 10 Surface Elevation Tables (SETs) at 3 sites on either side of the ICW (see **Figure 6.7)**. Within each of these locations, we increased the number of SETs (i.e., level of replication). We also found that we had to install more extensive boardwalks than originally planned due to the fragile nature of the marsh surface. This was particularly true at the Freeman Creek (Site 1), where a 55-m boardwalk was installed. Our concern for the integrity of the marsh surface in the experimental plots also led us to install 12-inch-wide fiberglass grating along the edge of each SET plot to further minimize disturbance of the marsh surface during research and monitoring data collection.

We will also modify the distribution of the remaining eight shoreline SETs (Sites 4–11) to be installed in support of Research Project CW-2. We anticipate that some of the shoreline SETs will be installed within the marsh fringe along the lower portion of the NRE and that a subset of the SETs will be installed along non-marsh shorelines to serve as benchmarks for high-resolution digital elevation models (DEMs). Ground-truthing and boat-based surveys of the NRE shoreline revealed that the areas of greatest interest to the Base, and those experiencing the greatest erosion, are already armored and are not vegetated. In those cases, the installation of SETs and horizon markers to measure sediment accretion are not appropriate approaches to quantifying shoreline erosion.

6.2.4.2.1 Objectives

No changes to this sub-section.

6.2.4.2.2 Relevance to the Base

No changes to this sub-section.

6.2.4.2.3 Scale

High-resolution measurements (mm) marsh surface elevations and sediment accretion will be obtained with SETs at Sites 1–9 and DEMs will be obtained at Sites 1–11. Tide gauges were installed at Mile Hammock Bay (Site 13) and Wallace Creek (Site 14) to represent high and low salinity, respectively.

6.2.4.2.4 Linkages within the Module and among other Modules' Monitoring Components

The location of monitoring stations has changed since the original Baseline Monitoring Plan; however, all monitoring activities in the surface elevation monitoring will still be performed at sites that were used for other Coastal Wetlands Module monitoring activities; see Figure 6-7 and Table 6-5. In addition, the Aquatic/Estuarine Module will monitor at Sites 1, 4, 5, 6, 7, 8, and 9. This duplication of sites with the Aquatic/Estuarine Module will allow us to examine the relationship between processes affecting marsh surface elevation and the structure and function of adjacent subtidal communities. We will coordinate sampling of the marsh behind the barrier island at Sites 2 with the Coastal Barrier Module monitoring activities. Changes in marsh surface elevation may have significant effects on variables measured by the Aquatic/Estuarine and Coastal Barrier modules, and by sharing sites, we will be able to assess these linkages.

6.2.4.2.5 Methods

Spatial/Site Locations

See Figure 6-7 for location of Coastal Wetlands Module sampling sites.

Sites 1–3: Replicate SETs were established at these stations within the ICW and are used for nutrient addition experiments (Research Project CW-1). At Freeman Creek (Site 1), six SETs were established to support fine-scale (±2-mm vertical resolution) measures of marsh elevation change in response to nutrient additions for Research Project CW-1. At the Onslow Beach Backbarrier (Site 2) and Mile Hammock Bay (Site 3), only two SETs were installed at each, one of which will serve as a control, and the other will receive the +N+P fertilizer for Research Project CW-1.

Sites 4–9: One SET will be established at each of these sites; the exact location of these sites will be dependent on the results from Research Project CW-2, on review and preliminary analysis of georectified photography of the shoreline, and proximity to shoreline stabilization structures. DEMs will be obtained for each these shoreline sites. We anticipate that some of these shoreline SETs will be installed within the marsh fringe along the lower portion of the NRE and that a subset of the SETs will be installed along non-marsh shorelines to serve as benchmarks for high-resolution DEMs. Ground-truthing and boat-based surveys of the NRE shoreline revealed that the areas of greatest interest to the Base, and those experiencing the greatest erosion, are already armored and not vegetated. In those cases, installation of SETs and horizon markers to measure sediment accretion are not appropriate approaches to quantifying shoreline erosion.

No changes to the temporal scale, personnel, or variables of this monitoring activity.

Field and Laboratory Procedures

Sampling Design and Collection

SET installation and reading. SETs will be installed in coastal wetlands following the procedures for a Deep RodSET described by Cahoon and colleagues (2002). Marker horizons and estimates of marsh surface elevation will be obtained as described by Cahoon (1999). SETs have become a standard method for obtaining sediment accretion rates in coastal wetlands, including marshes and mangroves. Additional

details on protocols, as well as a list of researchers and locations of SET installations around the world, are available at http://www.pwrc.usgs.gov/set.

Marsh elevation change will be determined by SETs in plots with a SET benchmark. Elevation changes in plots without SETs at Mile Hammock Bay and Onslow Beach Backbarrier sites will be determined by obtaining DEMs from each plot, using the nearby SETs as a vertical control, and using either a laser survey or real-time kinematic (RTK) global positioning system (GPS) to measure elevation change from the vertical benchmark. We estimate that our horizontal resolution using these techniques will be ±1 cm. Above-ground marsh primary production will be measured annually at each plot within a site.

Sediment particle size and organic matter analyses. No changes to this sample design.

DEMs. No changes to this sample design.

Water level/tide gauge: No changes to this sample design.

6.2.4.2.6 Data Analysis, Products, and Outcomes

No changes to this sub-section.

6.2.4.3 Marsh Groundwater and Nutrients

6.2.4.3.1 Objectives

No changes to this sub-section.

6.2.4.3.2 Relevance to the Base

No changes to this sub-section.

6.2.4.3.3 Scale

Three sites will be monitoring and characterizing the middle and lower portions of the New River Estuary (NRE) and the ICW. No sites are located in the lower salinity portion of the estuary.

6.2.4.3.4 Linkages within the Module and among other Modules' Monitoring Components

Monitoring of hydraulic throughput and marsh nutrient chemistry will be performed at three sites (i.e., Sites 1, 4, and 12) (see Figure 6-7) and is linked to Research Project CW-1 at Site 1 and provides the infrastructure for Research Project CW-3. All of these sites are positioned to coincide spatially with sampling stations in the Aquatic/Estuarine Module monitoring program.

6.2.4.3.5 Methods

Spatial/Site Locations

Marsh nutrients and groundwater will be collected at Sites 1, 4, and 12 (see **Figure 6-7**). Freeman Creek (Site 1) was selected because of it represents a tidally dominated euryhaline marsh, and it is co-located with other Coastal Wetlands Module monitoring activities and research projects. French Creek (Site 4) was selected because of its proximity to the G-10 impact area and its proximity to the MCBCL wastewater treatment plant. French Creek is also a representative meso-oligohaline, irregularly flooded marsh characteristic of the upper NRE. Traps Creek (Site 12) is a representative mesohaline, mixed-vegetation, pocket-marsh ecotype bisected by an incised stream channel. French and Traps creeks will serve nicely as model marshes for their respective ecotypes in terms of geomorphology, biology, and hydrology. However, another emergent marsh site in fresher water, such as a site originally proposed at Wallace Creek, that has similar geomorphology and hydrology would likely differ in terms of chemical

fluxes simply because it is less salty. One additional site further up the estuary would be beneficial to DCERP, but it is can not be accommodated with current resources. Instead of sampling at Wallace Creek, Traps Creek was selected because this site is co-located with creek and estuarine sites from the Aquatic/Estuarine Module.

Personnel

Dr. Eric Henry has been added to the project as a supporting researcher to Dr. Craig Tobias.

Field and Laboratory Procedures

Sampling Design and Collection

In Situ, Inc., level TROLL pressure transducers were chosen instead of the onset models originally proposed. This change was made to gain better saltwater compatibility for the transducer housing at a cost reduction of approximately 25%. The cost reduction will permit the purchase of additional transducers, which will result in better coverage and an improved estimate of water exchange in the marsh sub-surface.

6.2.4.3.6 Data Analysis, Products, and Outcomes

No changes to this sub-section.

6.3 Coastal Barrier Module

6.3.1 Introduction

No changes to this sub-section.

6.3.2 Coastal Barrier Module Monitoring Objectives and Activities

Minor changes were made to the spatial or temporal scale of some of the monitoring components, which are reflected in the revised **Table 6-7**, and are discussed in more detail in the following sub-sections.

Table 6-7. Coastal Barrier Module Monitoring Components

Component	Variable(s)	Spatial Scale	Temporal Scale
Meteorology (ocean)	Air temperature, wind speed, air pressure, solar radiation, wind direction	2 stations: 5 and 25 miles seaward of the New River Inlet	Continuous
Hydrodynamics	Horizontal and vertical wave velocity, wave heights, and period; direction; currents; water temperature	2 stations: 5 and 25 miles seaward of the New River Inlet	Continuous
	Horizontal and vertical wave velocity, wave heights, period, and direction	1 station: 500 m seaward of Riseley Pier	Continuous
	Tide data	Acquired from NOAA sites at Wilmington, NC; Charleston, SC; Norfolk, VA	Continuous
	Shoreline position, sand bar position, and morphology; near-shore wave period, direction, and height	Entire length of authorized beach and individual sites	Every 3 years (entire); semiannually and before/after storms (site specific)

Component	Variable(s)	Spatial Scale	Temporal Scale
Geomorphology	Shoreface bathymetry	Across the nearshore (2–10 m) depths throughout region of barrier island, including the New River Inlet, Browns Inlet, and individual sites	Every 3 years (entire); semiannually in Years 1, 3, and 4 (site specific)
	Barrier morphology	13 focus sites	Semiannually and before/after storms (site specific)
Sedimentology	Compaction, texture, and composition	20 samples from each of the 6 focus sites	Semiannually (May/September); before/after storms
Biology	Benthic invertebrate abundance and biomass by size class and community structure	2 replicate vertical transects from each of the 6 sites	Semiannually; before/after storms
	Shorebird and seabird abundance and community structure	Entire length of Onslow Beach, the New River Inlet, and Browns Inlet shorelines	Every 10 days (collected by Marine Corps Base Camp Lejeune [MCBCL])
	Dune, shrub, and marsh plants aerial cover; vegetation height; and surface elevation	Vertical transects at 6 sites and aerial photography of the entire length of Onslow Beach, the New River Inlet, and Browns Inlet shorelines	Vertical transects: Years 3 and 4; aerial photography: annually
	Site selection for sea turtle nests, false crawls, and success of nesting effort	Nesting and false crawls recorded along the entire length of Onslow Beach, the New River Inlet, and Browns Inlet shorelines	Nesting and false crawls assessed daily in season (data collected by MCBCL)

6.3.3 Benefit to MCBCL

No changes to this sub-section.

6.3.4 Coastal Barrier Module Monitoring Components

6.3.4.1 Hydrodynamics (Oceanographic data)

6.3.4.1.1 Objectives

No changes to this sub-section.

6.3.4.1.2 Relevance to the Base

No change to this sub-section.

6.3.4.1.3 Scale

No changes to this sub-section.

6.3.4.1.4 Linkages within the Module and among other Modules' Monitoring Components

No changes to this sub-section.

6.3.4.1.5 Methods

Spatial/Site Locations

The OB1M and OB5M moorings are no longer collecting data. Data will be downloaded from LEJ3, which is located at the same position as OB5M. The location of all of the instruments is shown in **Figure 6-10**. Information from OB1M and OB5M have been downloaded and stored.

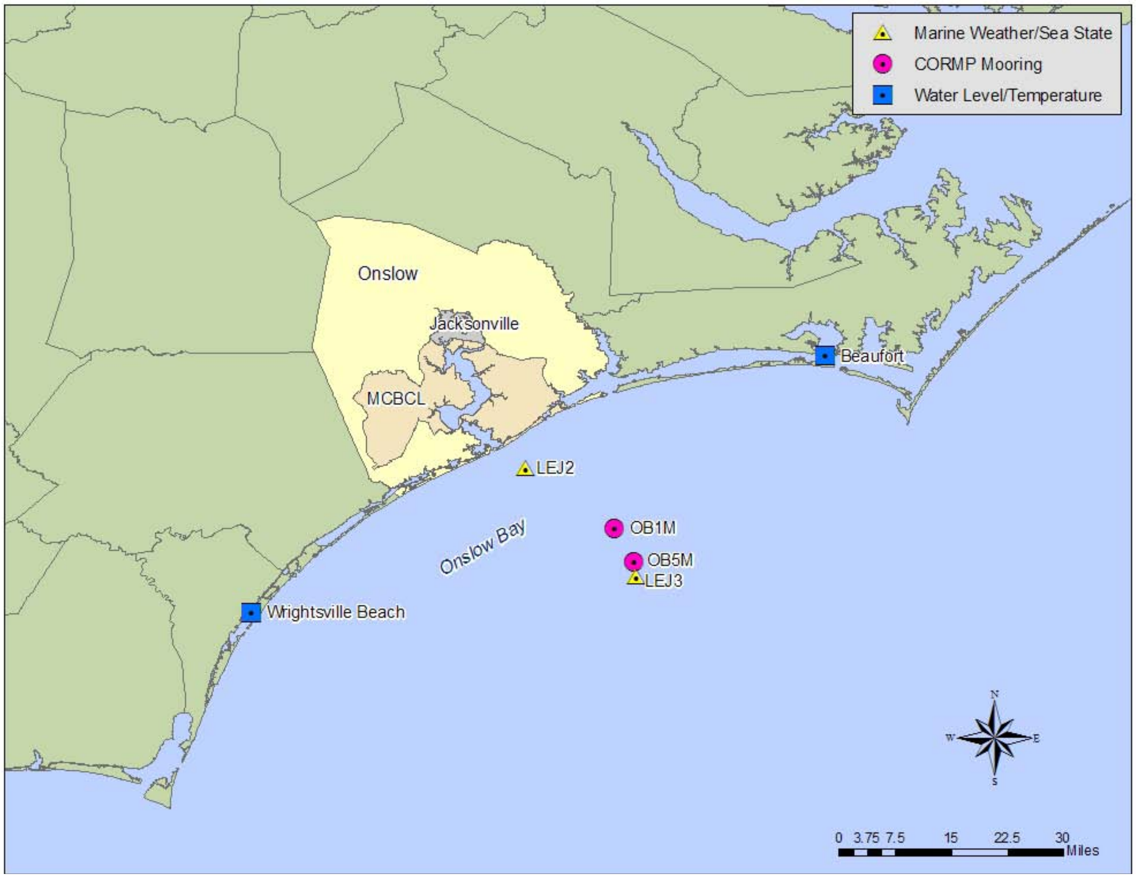


Figure 6-10. Offshore hydrodynamics (oceanographic) monitoring stations.

- **Buoy Data.** Acquire oceanographic data from the Coastal Ocean Research Monitoring Program
  - LEJ3 buoy, which has been collecting data since July 6, 2006, is located 25 miles from the New River Inlet, and it collects the same variables as listed for LEJ2 buoy in the Baseline Monitoring Plan.

Dr. Janelle Reynolds-Fleming has been added as a supporting researcher to Dr. Rick Leuttich.

There have been no other changes to this monitoring activity.

6.3.4.1.6 Data Analysis, Products, and Outcomes

No changes to this sub-section.

6.3.4.2 Hydrodynamics (ADCP)

6.3.4.2.1 Objectives

No changes to this sub-section.

6.3.4.2.2 Relevance to the Base

No changes to this sub-section.

6.3.4.2.3 Scale

No changes to this sub-section.

6.3.4.2.4 Linkages within the Module and among other Modules' Monitoring Components

No changes to this sub-section.

6.3.4.2.5 Methods

Spatial/Site Locations

After a testing both instruments, a Nortek Acoustic Wave and Current (AWAC) Profiler was purchased instead of TRD Instruments's Acoustic Doppler Current Profiler (ADCP) as stated in the DCERP Baseline Monitoring Plan. We determined that the Nortek AWAC Profiler is better for deciphering wave spectra than TRD Instruments's ADCP. Due to the increase cost on equipment, only one Nortek AWAC Profiler was purchased for the project. With only one instrument, we shifted our focus for coastal barrier island sustainability to Onslow Beach, which is the main area of study, and eliminated the station off North Topsail Beach. This equipment change does not change the temporal scale, variables to be collected, or field/laboratory procedures.

6.3.4.2.6 Data Analysis, Products, and Outcome

No changes to this sub-section.

6.3.4.3 Hydrodynamics (Mobile Radar)

No changes were made to this monitoring activity. However, **Figure 6-11** has been revised to illustrate the exact locations of the monitoring stations for the Coastal Barrier Module that were proposed in the DCERP Baseline Monitoring Plan, and **Table 6-8b** identifies these stations.

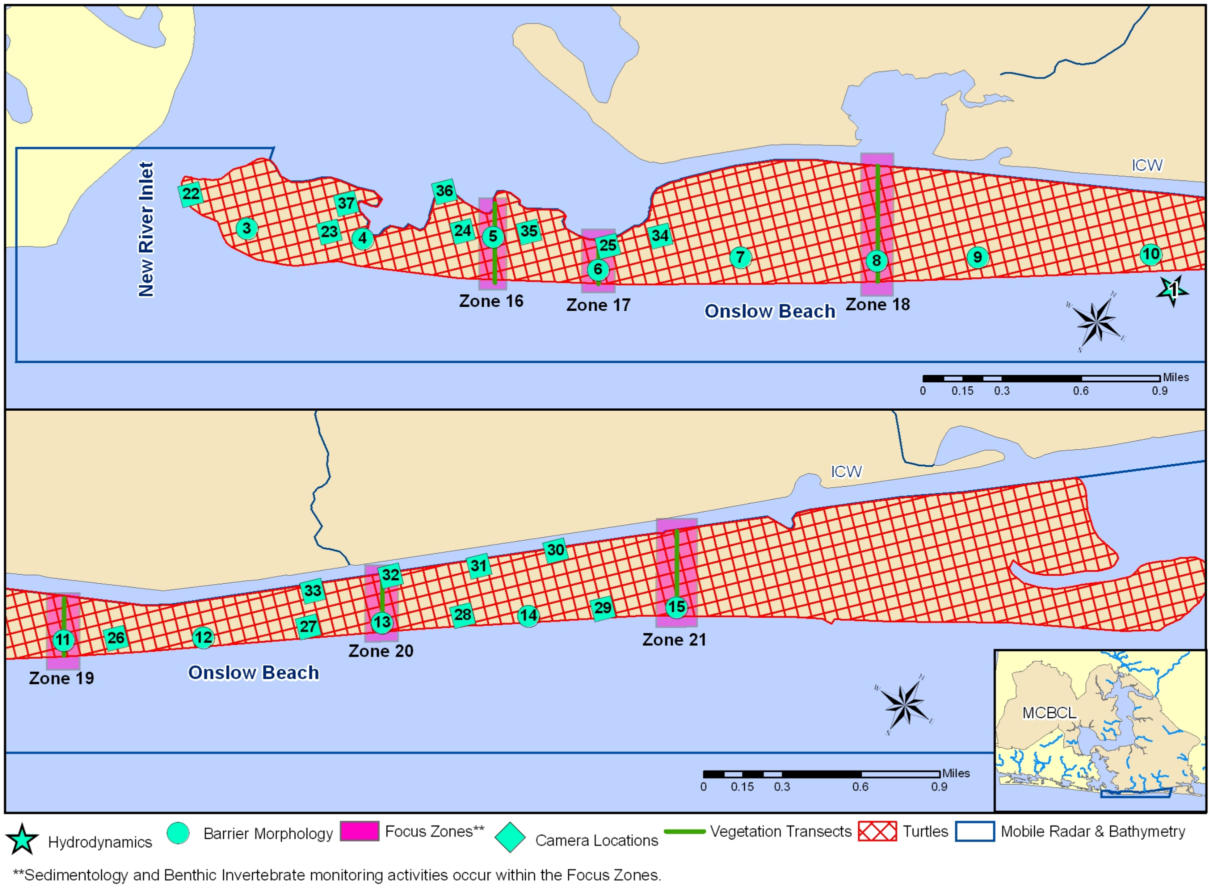


Figure 6-11. Coastal Barrier Module monitoring efforts.

Table 6-8b. Monitoring and Research Stations for the Coastal Barrier Module

Hydrodynamics	
Site 1: Riseley Pier	
Barrier Morphology	
Site 3: South Onslow Beach, training	Site 10: South Onslow Beach, training
Site 4: South Onslow Beach, training	Site 11: North Onslow Beach, recreation (Focus Site 19)
Site 5: South Onslow Beach, training (Focus Site 16)	Site 12: North Onslow Beach, recreation
Site 6: South Onslow Beach, training (Focus Site 17)	Site 13: North Onslow Beach, recreation (Focus Site 20)
Site 7: South Onslow Beach, training	Site 14: North Onslow Beach, recreation
Site 8: South Onslow Beach, training (Focus Site 18)	Site 15: North Onslow Beach, recreation (Focus Site 21)
Site 9: South Onslow Beach, training	

Focus Sites (Sedimentology and Benthic Invertebrate Monitoring)	
Site16: Off-road recreational vehicles (ORRVs) with overwash behind the beach	Site 19: Amphibious landings (low-use training activity)
Site17: ORRVs with salt marsh behind the beach	Site 20: Extensive human disturbance
Site 18: Amphibious landings (high-use training activity)	Site 21: Limited human disturbance
Camera Trapping Locations	
Site 22: Oceanside, south training, facing southeast	Site 30: Marsh, north recreation
Site 23: Oceanside, south training, facing northeast	Site 31: Marsh, north recreation
Site 24: Oceanside, south training, facing southeast	Site 32: Marsh, north recreation
Site 25: Oceanside, south training, facing southeast	Site 33: Marsh, north recreation
Site 26: Oceanside, north recreation, facing southeast	Site 34: Marsh, south training
Site 27: Oceanside, north recreation, facing southeast	Site 35: Marsh, south training
Site 28: Oceanside, north recreation, facing southeast	Site 36: Marsh, south training
Site 29: Oceanside, north recreation, facing southeast	Site 37: Marsh, south training, facing northeast

6.3.4.4 Shoreface Bathymetry

No changes to this monitoring activity.

6.3.4.5 Barrier Morphology

6.3.4.5.1 Objectives

No changes to this sub-section.

6.3.4.5.2 Relevance to the Base

No changes to this sub-section.

6.3.4.5.3 Scale

The area and frequency of mapping have been modified from that presented in the DCERP Baseline Monitoring Plan. Originally, the entire coastal barrier was to be mapped once every 3 years, and 6 focus sites were to be mapped semiannually and before and after storms. In November 2007, we attempted to map the entire coastal barrier island and learned that this was not possible because there is no accessible beach exposed at high tide. This limited us to 4 hours of mapping per day, which does not provide enough time to map the whole coastal barrier in 1 week. If the coastal barrier is mapped over a 1-month period, data collected at the start of the period would not merge with data collected at the end of the period because of the large morphologic changes that can occur across a coastal barrier during a 1-month period. Furthermore, devoting 1 month for mapping the topography of an entire coastal barrier is not cost effective. The modified methods include monitoring 13 coastal barrier sites semiannually as opposed to the original plan in which the entire coastal barrier morphology would be mapped only every 3 years and at 6 barrier sites semiannually.

6.3.4.5.4 Linkages within the Module and among other Modules' Monitoring Components

No changes to this sub-section.

6.3.4.5.5 Methods

Spatial/Site Locations

The topography of 13 focus sites from the ocean shoreline of Onslow Beach to the top of the first dune line, excluding the no-go impact zone at the north end of Onslow Beach, will be mapped using a Riegl LMS-Z210ii three-dimensional (3-D) terrestrial laser scanner and an RTK GPS. Photomosaics (360 degrees) of each scan position are also created from a digital camera mounted on top of the laser scanner (**Figure 3.3-12**). These sites are equally spaced across the coastal barrier, include the same areas where the other monitoring activities are taking place, and experience off-road driving, amphibious military assault training landings, and human disturbances (Figure 6-11). This activity will still coincide with the bathymetry mapping effort. These two datasets will be merged to estimate the entire volume of the barrier.

Temporal Considerations

Morphology will be assessed semiannually at 13 focus sites and before and after replicate storm events at these focus sites.

6.3.4.5.6 Data Analysis, Products, and Outcomes

No changes to this sub-section.

6.3.4.6 Sediment Compaction, Texture, and Composition

No changes were made to this monitoring activity.

6.3.4.7 Benthic Invertebrates

No changes were made to this monitoring activity.

6.3.4.8 Surf Fish and Sea Turtles

No changes were made to this monitoring activity.

6.3.4.9 Shorebirds and Seabirds

No changes were made to this monitoring activity.

6.3.4.10 Dune, Shrub, and Marsh Plants

This activity will not start until fall 2009. No changes were made to this monitoring activity.

6.4 Terrestrial Module

6.4.1 Introduction

No changes to this sub-section.

6.4.2 Terrestrial Module Monitoring Objectives and Activities

No changes to this sub-section.

6.4.3 Benefit to MCBCL

No changes to this sub-section.

6.4.4 Terrestrial Module Monitoring Components

6.4.4.1 Changes in Plant Species Composition, Diversity, and Distribution

The primary modifications to the DCERP Baseline Monitoring Plan are to give priority to vegetation plots established within MCBCL with an emphasis on identifying a focus set of species and site indicators and developing an efficient sampling and analytical protocol that can easily be transitioned for use by MCBCL staff.

6.4.4.1.1 Objectives

No changes to this sub-section.

6.4.4.1.2 Relevance to the Base

No changes to this sub-section.

6.4.4.1.3 Scale

No changes to this sub-section.

6.4.4.1.4 Linkages within the Module and among other Modules' Monitoring Components

No changes to this sub-section.

6.4.4.1.5 Methods

Spatial/Site Locations

The basic dataset for this monitoring activity will come from data previously gathered on the installation by the MCBCL staff, the Carolina Vegetation Survey (CVS) (Peet et al., 1998), and plantation samples established by Dr. Joan Walker. The data from the MCBCL staff comprise 73 georeferenced and permanently marked sites at which 4 standard photos were taken in each of the cardinal compass directions. These permanent points were located across MCBCL to represent the full array of site types and management activities on the Base. The CVS (38 plots) and Dr. Walker samples (29 plots) are based on 0.1 hectare (ha) sampling plots that have been evaluated using the CVS protocols. They were sampled in 1993 and in 2003, respectively. The CVS data are focused primarily on relatively undisturbed sites, whereas Dr. Walker's data were purposely located in plantation locations that received assorted forestry management treatments. The CVS sites are spatially clustered, and it is likely that only 10 to 12 of these sites will be appropriate for our objectives. After reviewing the geographical distribution of the selected plots, we will add additional plots where needed to ensure a more complete representation. Our goal is to monitor approximately 100 foundation plots across MCBCL over a 2-year period (approximately 50 sites/year).

6.4.4.1.6 Data Analysis, Products, and Outcomes

No changes to this sub-section.

6.4.4.2 Assessment of Land Use/Land Cover Change

The DCERP Baseline Monitoring Plan has two IKONOS images being purchased in 2007 and 2009. Due to cost constraints, multiple IKONOS image purchases are not likely. Ideally, with Base expansion for new personnel planned over the next 5 years, one image purchase should be before any new construction (the existing 2006 IKONOS data), and a second purchase should occur after the construction, although this time frame may be outside the initial 5-year DCERP contract period. If the raw data from previous IKONOS purchases can be located (2004 and 2006), a single new acquisition could be matched with these data.

6.4.4.2.1 Objectives

The objectives of this monitoring activity are to assess historical and future changes in land use/land cover to provide a comprehensive estimate of ecosystem change at regular intervals for MCBCL.

The Landscape Change Detection monitoring activity will identify change at two scales:

- Moderate resolution regional change within the New River watershed.
- High-resolution change within MCBCL.

6.4.4.2.2 Relevance to the Base

In addition to the relevance previously listed in the DCERP Baseline Monitoring Plan, the products from the land use/land cover change analysis will directly benefit the Base in preparing an Environmental Impact Statement (EIS) needed for the 202k staff up. The planned staff increase could bring 5,000 to 7,000 U.S. Marines to Camp Lejeune by 2011. The historical change will provide a baseline for the EIS, representing the past alterations and current conditions before new development (e.g., construction of training facilities, housing) at MCBCL begins as a result of this substantial increase in Base population. This allows for pre- and post-development assessments, which will benefit both DCERP research efforts and can be used as an input to the MCBCL's EIS process.

6.4.4.2.3 Scale

No changes to this sub-section.

6.4.4.2.4 Linkages within the Module and among other Modules' Monitoring Components

No changes to this sub-section.

6.4.4.2.5 Methods

Temporal Considerations

In addition to the Landsat Thematic Mapper (TM) scenes that will be acquired yearly to monitor change in the future, Landsat also will provide a history of change, with cloud-free images available for MCBCL beginning in 1984. An extensive image search was performed, and the likely sequence of dates will be 1984, 1998 or 2000, and 2007. Future increments of change detection using Landsat will be dependent on the continued health of the satellite. There is a significant chance that the current Landsat satellites will be non-functional before replacements are launched in 2011, which would directly impact the time period covered by this DCERP monitoring activity.

We are still trying to locate existing IKONOS imagery from 2004 or 2006 to provide the baseline conditions for the high-resolution imagery analysis; however, this imagery will have some processing challenges due to its high spatial resolution and the small footprint of each scene (multiple separate scenes will be needed to cover all of MCBCL). IKONOS also needs to be specifically tasked; unlike Landsat, no data are collected unless specifically requested. Funds allocated for this monitoring activity would be used to purchase a future set of IKONOS imagery.

Procedures

Change detection methods will be based on Change Vector Analysis (CVA) methodology. CVA detects change in a pair of multispectral images. This does not depend on the images first being classified; therefore, it is not constrained to only change within land cover types and is far less labor intensive. This will be referenced to existing land use/land cover maps of MCBCL and the surrounding watershed. Several land use/land cover maps exist, including the National Landcover Database of 1992 and 2001, the

North Carolina land use/land cover database, and the N.C. Gap Analysis Program vegetation map, which is the most detailed of the land use/land cover data.

6.4.4.2.6 Data Analysis, Products, and Outcomes

CVA change detection will provide locations of all pixels in the landscape that have changed between image dates. This provides functional change types, such as loss of greenness and loss of wetness, that represent real ecological differences. This will also be cross-walked to existing land use/land cover maps of MCBCL to specify change types in terms of class types. These changes will be produced for each image pair, for both historical and future image acquisitions.

6.5 Atmospheric Module

6.5.1 Introduction

No changes to this sub-section.

6.5.2 Atmospheric Module Monitoring Objectives and Activities

The objective of the Atmospheric Module's monitoring activities is to characterize the role of air quality in MCBCL's ecosystem by capturing meteorological and climatological processes and their occurrence in different temporal and spatial scales in support of various research projects that consider and depend on certain biosphere-atmosphere interactions (**Table 6-12**).

Table 6-12. Atmospheric Baseline Monitoring

Component	Variables	Temporal Scale	Spatial Scale
Meteorology	WS, WD, BP, RH, PAR	Minutes to hourly	4 existing stations: Riseley Pier (south), GSRA—ground and tower (west), and MCASNR (north)
	WS, WD, BP, T, RH, VIS, CIG, FT, and FM	Minutes to hourly	5 stations off Base but within Onslow County
	Precipitation	Event based	17 stations both on Base and off Base
EPA criteria pollutants	O_3	Minutes to hourly	3 existing stations: Riseley Pier (south), GSRA tower (west), and MCASNR (north)
	PM_{10} and $PM_{2.5}$ mass	Minutes to hourly	2 existing stations: Riseley Pier (south) and GSRA tower (west)

BP = barometric pressure, CIG = ceiling, FT = fuel temperature, FM = 10-hour fuel moisture, GSRA = Greater Sandy Run Area, MCASNR = Marine Corps Air Station New River, O_3= ozone, PAR = photosynthetic active radiation, $PM_{2.5}$ and PM_{10} = fine and coarse particulate matter, RH = relative humidity, RP = Riseley Pier, T = temperature, WD = wind direction, WS = wind speed, VIS = visibility

6.5.3 Benefit to MCBCL

No changes to this sub-section.

6.5.4 Atmospheric Module Monitoring Components

6.5.4.1 Combined Meteorology, O_3, and Fine and Coarse Particulate Matter

Due to constraints on the equipment budget, particulate matter (PM) measurements were eliminated at MCASNR because of its access restrictions and inherent logistical difficulties; therefore, PM measurements are now focused only at the Riseley Pier (RP) and Greater Sandy Run Area (GSRA) tower sites. To summarize, the following modified equipment plan has been established:

1. RP: The data sampling rate, access, and download frequencies currently in place at the RP site and managed by the National Oceanic and Atmospheric Administration (NOAA), are not high enough to meet DCERP’s requirements. In addition, access to download NOAA’s data is limited; therefore, Dr. Karsten Baumann decided to use a data acquisition system (DAS) for independent access and harmonized downloads from the other two sites.
2. GSRA tower: An enclosed air-conditioned and electrically powered (wired) shelter on top of a 40-m tower approximately 3 km north of the existing GSRA ground site at SR-7 (near Landing Zone [LZ] Snipe) will be used to deploy the additional meteorological sensors, including photosynthetically active radiation (PAR), ozone (O_3). and PM monitors. The proximity of the GSRA tower site to the GSRA ground site allows for investigation into near-surface boundary layer dynamics and air mass stratification. The GSRA tower site’s location is relatively central, but west and upwind from the New River and the K-2 impact areas (assuming predominantly westerly flow under strong synoptic pressure gradient conditions), and east from prescribed burning (PB)-managed lands on and off Base (Holly Shelter). Therefore, we will be able to associate plume encounters with different fuels from using PB activity records.
3. MCASNR: PAR and O_3 sensors will be deployed at an air-conditioned site/room near MCASNR, allowing for the use of the same data retrieval as the other two stations. High frequency (1 Hz) raw data can be routinely processed for quality assurance/quality control in the same manner as and together with the data from the other two sites.

6.5.4.1.1 Objectives

No changes to this sub-section.

6.5.4.1.2 Relevance to the Base

No changes to this sub-section.

6.5.4.1.3 Scale

The selected monitoring sites in **Figure 6-17** (revised) cover the full vegetation diversity encountered along the hydrological gradient from the coastal area (Site 1–Riseley Pier), mixed pocosin/loblolly pine in the GSRA (Sites 3 and 4) to the west, and longleaf pine dominated areas to the north (Sites 2 and 5).

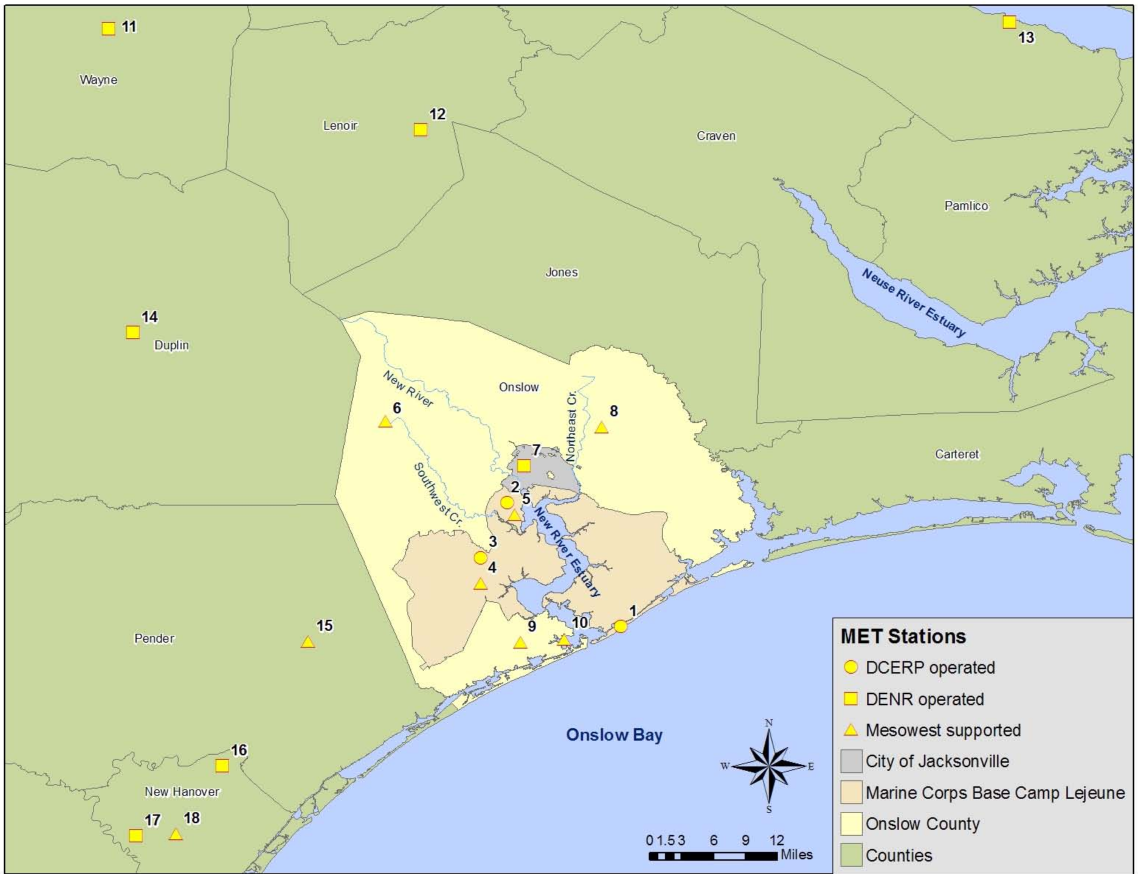


Figure 6-17. Location of current meteorological stations supplemented with continuous O_3, $PM_{2.5}$ and PM_{coarse} measurements for the comprehensive analysis of atmospheric pollutants transport in support of collocated wet and dry deposition measurements.

Table 6-14 provides a description of the monitoring stations and identifies which parameters are collected at each station. Sites 1, 2, and 3 are operated by Dr. Baumann and are the main focus of this monitoring component. However, data will be acquired from the N.C. Department of Natural Resources and from data reported through the MesoWest Web site (at http:www.met.utah.edu/mesowest) run by the University of Utah's Department of Meteorology for other stations in the region.

Table 6-14. Atmospheric Monitoring Stations On and Off Base

Site No.	Station Name	Maintained By	Latitude (North)	Longitude (East)	Parameters
1	Riseley Pier	DCERP	34.5542	-77.2965	BP, T, RH, WS, WD, PPT, PAR, O_3, $PM_{2.5}$, PM_{10}
2	Recycling Center near MCASNR	DCERP	34.722647	-77.450969	O_3, PAR
3	GSRA tower	DCERP	34.64794	-77.4874	BP, T, RH, WS, WD, PAR, O_3, $PM_{2.5}$, PM_{10}
4	GSRA ground	MesoWest	34.6119	-77.4875	T, RH, WS, WD, RAD, PPT, FT, FM
5	MCASNR	MesoWest	34.70583	-77.44083	BP, T, RH, WS, WD, VIS, CIG, PPT
6	Jacksonville Airport	MesoWest	34.83333	-77.61667	BP, T, RH, WS, WD, VIS

Site No.	Station Name	Maintained By	Latitude (North)	Longitude (East)	Parameters
7	Onslow County	NC DENR	34.77280	-77.42800	$PM_{2.5}$, PM_{10}
8	Hofmann Forest	MesoWest	34.82500	-77.32190	BP, T, RH, WS, WD, RAD, PPT, FT
9	Sneads Ferry, secondary	MesoWest	34.53154	-77.43320	BP, T, RH, WS, WD
10	Sneads Ferry, primary	MesoWest	34.5364200	-77.3733800	BP, T, RH, WS, WD
11	Wayne County	NC DENR	35.3692000	-77.9939000	$TEOM_{2.5}$, $PM_{2.5}$, PM_{10}, WS, WD
12	Lenoir County	NC DENR	35.2315000	-77.5688000	O_3, $PM_{2.5}$, T, RH, WS, WD, RAD, PPT
13	Beaufort County	NC DENR	35.3778000	-76.7669000	SO_2
14	Duplin County	NC DENR	34.9548000	-77.9608000	$PM_{2.5}$
15	Back Island Holly Shelter	MesoWest	34.53280	-77.72190	BP, T, RH, WS, WD, RAD, PPT, FT, FM
16	New Hanover County Castle	NC DENR	34.3641670	-77.8386120	O_3, SO_2, $TEOM_{2.5}$, $PM_{2.5}$
17	New Hanover County Wilmington	NC DENR	34.2684000	-77.9565000	SO_2
18	Wilmington International Airport	MesoWest	34.2705600	-77.9025000	BP, T, RH, WS, WD, VIS, CIG, PPT

BP = barometric pressure, CIG = ceiling, FT = fuel temperature, FM = 10-hour fuel moisture, GSRA = Greater Sandy Run Area, MCASNR = Marine Corps Air Station New River, NC DENR = N.C. Department of Environment and Natural Resources, O_3= ozone, PAR = photosynthetic active radiation, $PM_{2.5}$ and PM_{10} = fine and coarse particulate matter, PPT = precipitation , RH = relative humidity, RP = Riseley Pier, T = temperature, $TEOM_{2.5}$ = $PM_{2.5}$ measured with a tapered element oscillating microbalance, WD = wind direction, WS = wind speed, VIS = visibility

6.5.4.1.4 Linkages within the Module and among other Modules' Monitoring Components

No changes to this sub-section.

6.5.4.1.5 Methods

Spatial/Site Locations

The existing stations are summarized in Table 6-14. These sites surround the Base to the north (Hofmann Forest–Site 8 and Jacksonville Airport–Site 6), west (Holly Shelter–Site 15), southwest (Sneads Ferry–Sites 9 and 10), and south (NOAA buoy–see Section 6.3.4.1). PAR sensors will be installed and operated at MCASNR and RP sites, as well as on top of a 40-m tower (SR-7 near LZ Snipe), approximately 3 km north from the GSRA site. This site will be equipped with additional barometric pressure, temperature, relative humidity, wind speed, and direction sensors (contributed to DCERP by Atmospheric Research & Analysis, Inc.), allowing for monitoring of more regional conditions due to the measurement's height above ground. At each of the three PAR-equipped stations (Table 6-14), analog signals from the added met sensors, one O_3 analyzer, one $PM_{2.5}$, and one PM_{10} nephelometer (only at RP and GSRA), are being acquired via independent data loggers at a sampling rate of 1 Hz, and reduced, quality assured, and reported as 5-minute averages. All meteorological parameters are being continuously measured and evaluated year-round to establish a detailed climatology for the different ecosystems on MCBCL. In contrast to the regulatory network, O_3 is being monitored year round.

6.5.4.1.6 Data Analysis, Products, and Outcomes

No changes to this sub-section.

6.5.4.2 EPA Criteria Pollutants (O_3, SO_2, $PM_{2.5}$)

6.5.4.2.1 Objectives

The purpose of this section is to describe how DCERP will use existing state-government-operated air quality monitoring stations' data to enhance an understanding of air quality in MCBCL's airshed.

6.5.4.2.2 Relevance to the Base

No changes to this sub-section.

6.5.4.2.3 Scale

These sites are fixed within a sub-regional scale up to 100 km; see Table 6-14 and Figure 6-17. Delete Figure 6-18 from the DCERP Baseline Monitoring Plan. The revised Figure 6-17 in this Addendum combines information for the original Figures 6-17 and 6-18 in this document.

6.5.4.2.4 Linkages within the Module and among other Modules' Monitoring Components

No changes. to this sub-section

6.5.4.2.5 Methods

Spatial/Site Locations

Figure 6-17 and Table 6-14 in the Section 6.5.4.1 illustrate the location and description of the stations were additional data will be collect and analyzed.

Temporal Considerations

Variable depending on the data stream.

6.5.4.2.6 Data Analysis, Products, and Outcomes

No changes to this sub-section.

6.6 Adapting the Baseline Monitoring Plan

No changes to this sub-section.

7.0 Data Management Module

No changes to this section.

8.0 Quality Assurance

No changes to this section.

9.0 Transition Monitoring Program to MCBCL

No changes to the section.

10.0 Measurements of Success

No changes to this section.

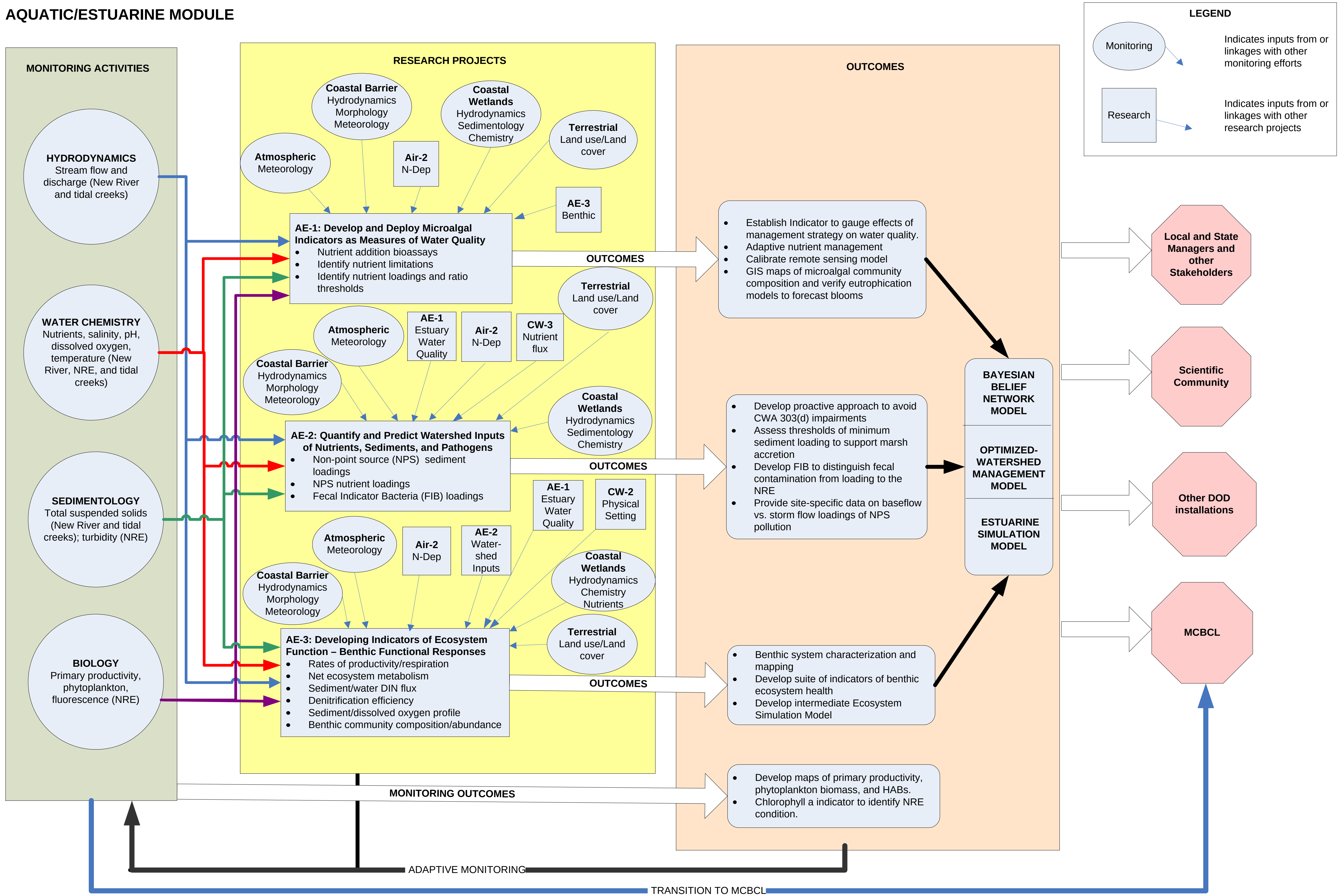
11.0 Literature Cited

No changes to this section.

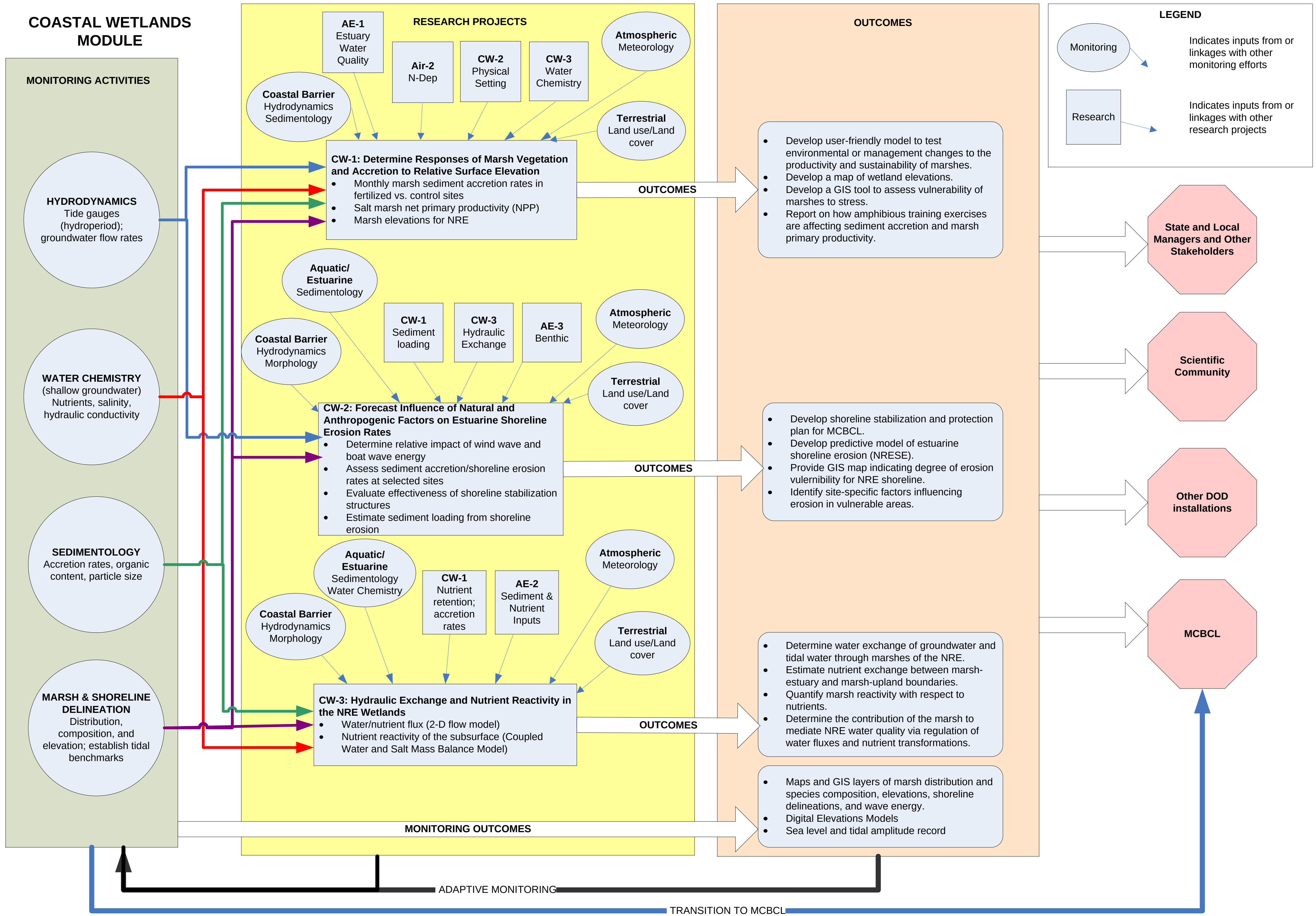
Appendix E

Ecosystem Module Roadmaps

AQUATIC/ESTUARINE MODULE

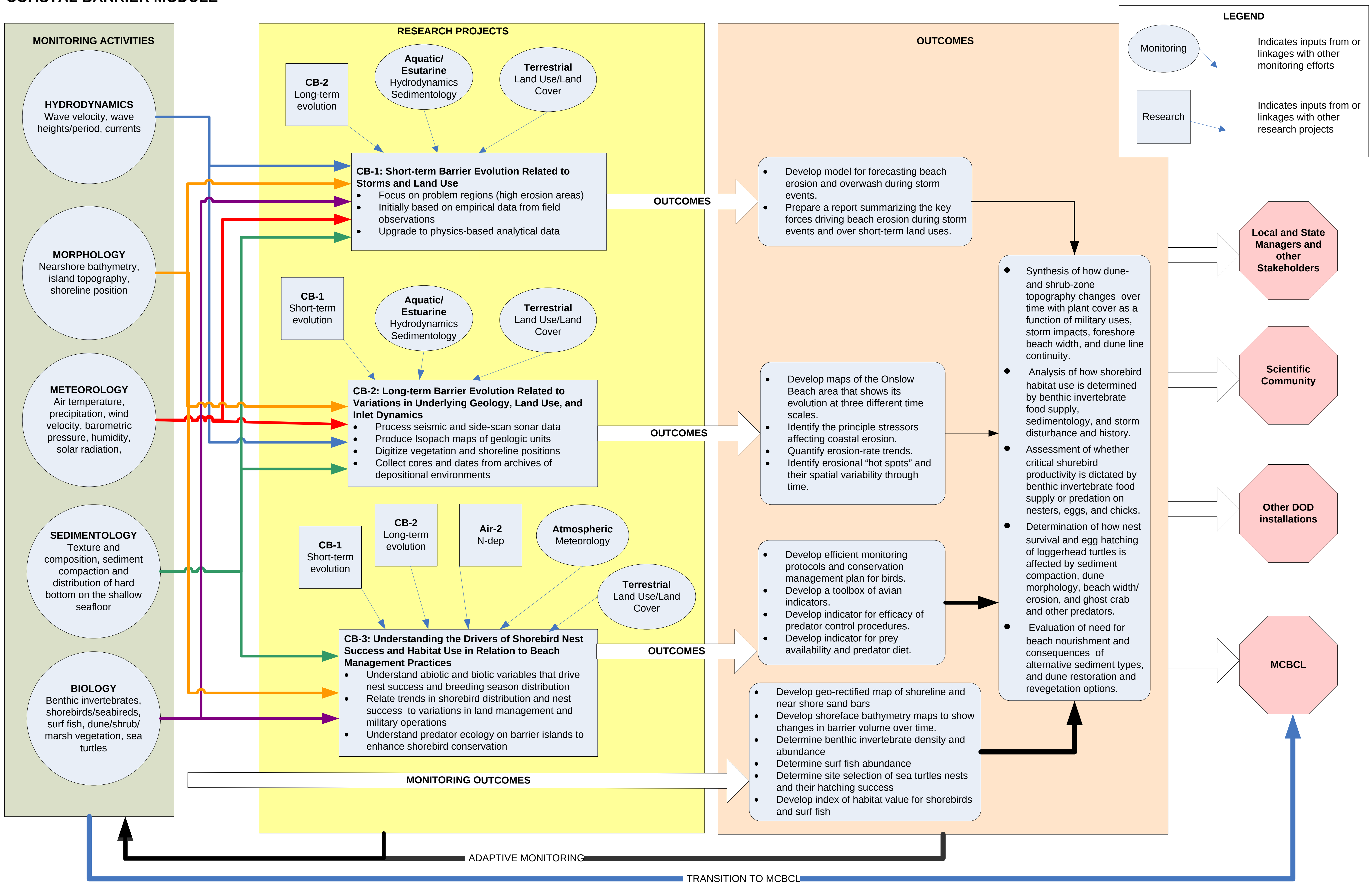


Aquatic/Estuarine Module

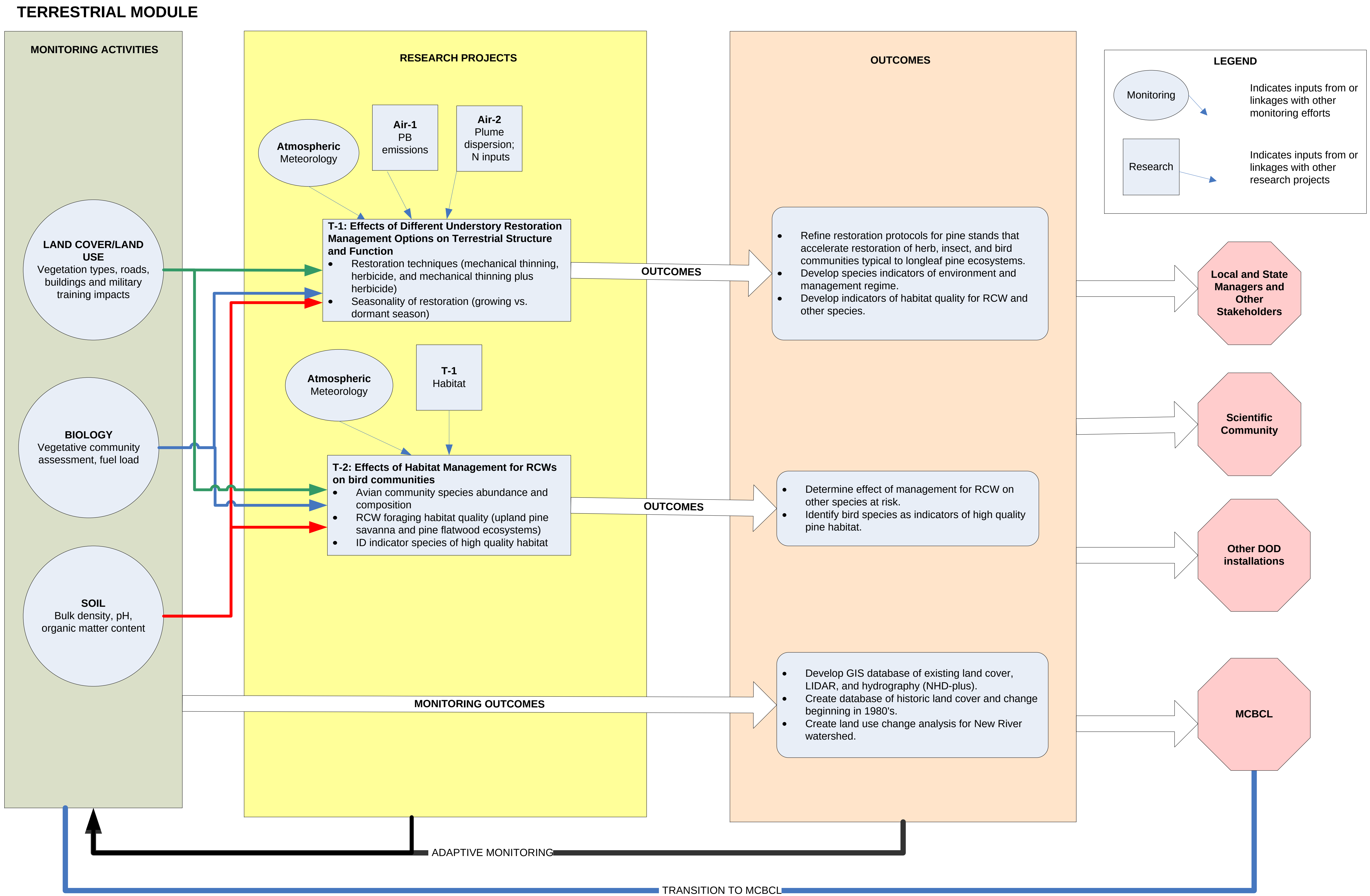


Coastal Wetlands Module

COASTAL BARRIER MODULE

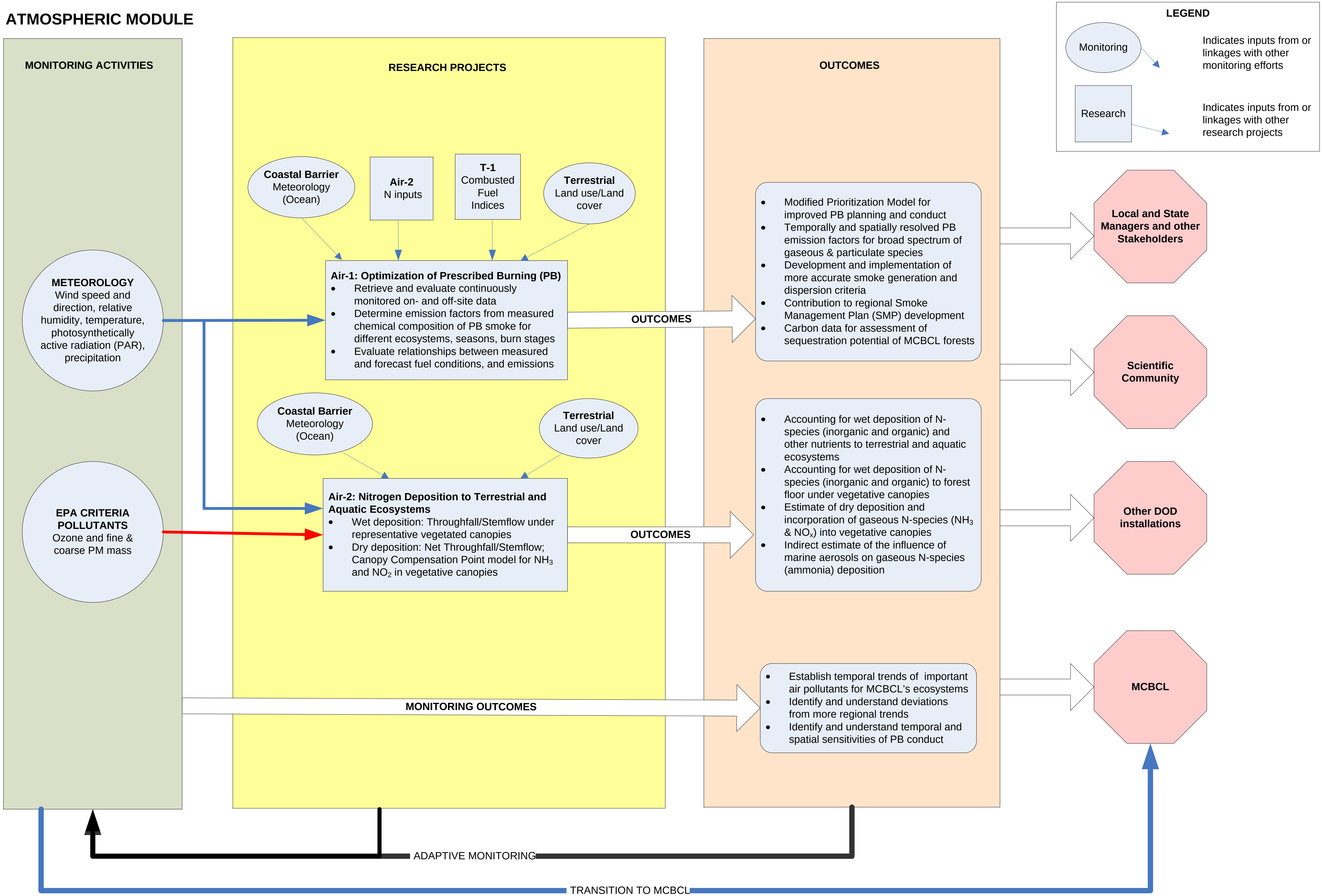


Coastal Barrier Module



Terrestrial Module

ATMOSPHERIC MODULE



Atmospheric Module